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Growth, nutrient uptake and yield of direct seeded rice as influenced by weed management practices

LEKSHMI SEKHAR¹, AMEENA M.², NIMMY JOSE³ AND SHALINI PILLAI P.⁴

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ABSTRACT

A field experiment was conducted during the *kharif* seasons of 2018 and 2019 at the College of Agriculture, Kerala Agricultural University, Vellayani, Kerala, to evaluate the effect of herbicides and herbicide combinations (both premix and tank mix) on the weed management, growth, nutrient uptake and yield of direct seeded rice (DSR). The experiment was laid out in randomized block design with three replications. Nine weed control treatments were used, including sole application of three herbicides (cyhalofop butyl @ 80 g/ha, bispyribac sodium @ 25 g/ha, fenoxaprop-p-ethyl @ 60 g/ha), five herbicidal combinations (premix of penoxsulam 1.02% + cyhalofop-butyl 5.1% @ 150 g/ha; tank mix (TM) of cyhalofop butyl @ 80 g/ha + carfentrazone ethyl @ 20 g/ha, TM of bispyribac sodium @ 25 g/ha + cyhalofop butyl @ 80 g/ha, TM of bispyribac sodium @ 25 g/ha + fenoxaprop-p-ethyl @ 60 g/ha and stale seedbed with TM of glyphosate @ 800 g/ha + oxyfluorfen @ 150 g/ha at 15-20 days to knock out weeds followed by TM of cyhalofop butyl @ 80 g/ha + carfentrazone ethyl @ 20 g/ha at 3–4 stage of weed), and hand weeding (HW) twice at 20 and 40 days after sowing. Weeds removed 27.72, 4.61 and 67.95 kg of N, P and K/ha, respectively at 45 days after treatment application (DATA) under unweeded condition in direct seeded rice. Herbicidal treatments enhanced grain yield by 23.89 to 58.84 % and herbicide combinations increased grain yield by 56 to 59 % compared to the unweeded control in direct seeded rice. Tank mix combination of bispyribac sodium @ 25 g/ha + fenoxaprop-p-ethyl @ 60 g/ha and bispyribac sodium @ 25 g/ha + cyhalofop butyl @ 80 g/ha and premix combination of penoxsulam + cyhalofop butyl @ 150 g/ha recorded higher nutrient uptake and grain yield (5.03, 4.76 and 4.79 t/ha, respectively) and were on par to HW twice. Unweeded control recorded the lowest pooled grain yield (2.07 t/ha) and uncontrolled weed competition resulted in 59.95 % reduction in grain yield in direct seeded rice.

Key words: Crop competition, Herbicide combinations, Herbicide interactions, Nutrient removal, Nutrient uptake, Yield reduction

With global grain demand projected to double by 2050, the challenge lies in substantially enhancing rice production, given its status as the world's most important food crop. This semi-aquatic annual grass from tropical Asia, plays a vital role in global food security being one of the most important staple foods for more than 3.5 billion people all over the world (CGIAR, 2023). India is the second largest producer and consumer of rice after China, contributing 21% of the global rice production (APEDA,

2021). In Kerala, it is grown in an area of 1.91 lakh ha with total production of 5.87 lakh tonnes and productivity of 3070 kg/ha during 2019-20 (GOK, 2022). However, the productivity of rice, particularly in direct-seeded systems, faces significant challenges due to weed infestations. Weeds are one of the major biotic constraints, causing significant yield reductions and economic losses in direct seeded rice. In direct-seeded rice systems, where rice seeds are sown directly into the field without transplanting, weeds can establish and proliferate more easily, posing a greater threat to crop yields. As the weeds emerge concurrently with rice and farmers are rarely able to use standing water to inhibit weeds in the early stages of growth, the risks of crop yield loss due to competition from weeds in direct seeded rice (DSR) are greater than in transplanted rice (Chauhan and Johnson, 2010).

Even though DSR eliminates the need for labour-intensive and costly transplanting, it is also associated with

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increased weed pressure. Weed growth caused 52.2% reduction in grain yield in the wet direct seeded rice (WDSR), as reported by Umkhulzum and Ameena (2019), and highlighted the importance of keeping the field weed-free at critical periods of crop growth. The unfavourable environment caused by weeds throughout the crop cycle in the weedy check plots in dry DSR resulted in shorter panicle length and lower thousand grain weight as reported by Chaudhary *et al.* (2018). Weeds dominate the crop habitat and limit yield potential due to their adaptability and rapid growth and show dynamic spatial variations both within and across fields, along with temporal fluctuations during and between seasons. Thus, the potential benefits of direct seeding must be weighed against the risks posed by increased weed pressure (Ameena *et al.*, 2024). Therefore, it is important to manage weeds effectively in order to maintain soil fertility and ensure sustainable crop production. According to Singh *et al.* (2018), the annual loss of rice grain yield in India is estimated to be more than 15 million tonnes due to weed infestation. Weeds can have a significant impact on nutrient removal in agricultural systems, leading to soil nutrient depletion and decreased soil fertility over time. This can lead to reduced crop productivity, increased costs for fertilizer applications, and lower farm profitability (Kumar *et al.*, 2024). Weed competition in wet direct seeded rice limited the availability of nutrients to the crop, negatively affecting growth and yield characteristics, leading to increased competition and ultimately reduced rice yield (Reddy and Ameena, 2021a).

The use of herbicides has emerged as a key strategy for controlling weeds, offering a reliable and efficient means to reduce weed pressure and minimize yield losses. Despite the benefits, relying solely on single herbicide applications can be insufficient due to the diversity of weed species and the potential for herbicide resistance development. Herbicides has become an inevitable practice in DSR due to the enormous and extensive population of weeds, coupled with the paucity and high cost of labour for manual weeding, despite concerns about weed shifts, herbicide resistance and environmental trade-offs. A variety of herbicides have been used to control weeds in the DSR, though chemical management methods focused on a single herbicide may be ineffective due to their limited weed control spectrum. To address these challenges, the tank mix application of herbicides has gained attention. This approach involves combining multiple herbicides with different modes of action in a single application. By doing so, it targets a broader spectrum of weeds and reduces the likelihood of resistance development, enhancing overall weed control efficacy. Tank mix applications provide several advantages, including improved weed management, reduced labour and operational costs, and better crop safety. This method is particu-

larly beneficial in direct-seeded rice systems, where timely and effective weed control is crucial for ensuring optimal growth and maximum yield (Arya and Ameena, 2016). Herbicide mixtures are regarded as effective tools for cost-effective weed control in intensive agriculture, and herbicide combinations (both tank and proprietary mixtures) broaden the weed control spectrum with a single application (Yogananda *et al.*, 2022). Using two or more herbicides may become a component of a more effective and integrated technique in the future to achieve better control of complex weed flora in DSR. Herbicide mixes will help to avoid the resistance problem and weed population shifts that are always a concern when using a single herbicide (Duary *et al.*, 2015). Tank mixing of appropriate herbicide formulations is a potential economic approach for dealing with weed shift, herbicide resistance and broad-spectrum weed management. In this context, the present study aimed to evaluate the effectiveness of various weed management practices, including herbicides and herbicide combinations, in reducing weed competition and improving the growth, nutrient uptake, and yield of DSR.

MATERIALS AND METHODS

The experiment was carried out during the *kharif* season of 2018 and 2019 at the Integrated Farming System Research Station in Thiruvananthapuram (8° 47' N latitude, 76° 96' E longitude; 40 m above mean sea level) under Kerala Agricultural University. The soil of the experimental site was sandy clay loam in texture under the typical tropofluent, deep riverine alluvium with a pH of 4.84 (very strongly acidic) and 5.56 (moderately acidic), respectively during 2018 and 2019. The soil was low in available N (225.8 kg/ha during 2018 and 175.6 kg/ha during 2019), high in available P (32 kg/ha during 2018 and 29 kg/ha during 2019), and K (450.9 kg/ha during 2018 and 377.6 kg/ha during 2019), as well as organic carbon (1.55% during 2018 and 2.18% after flood with silt deposition during 2019).

The plot size of each experimental unit was 5 m × 4 m. The rice variety 'Uma' (MO-16) was directly sown in the field at a seed rate of 100 kg/ha. The crop was managed uniformly, except for weed control. The experiment comprised nine weed control treatments, including the sole application of three herbicides, five herbicidal combinations, and hand weeding (HW) twice at 20 and 40 days after sowing (DAS). The herbicidal treatments were cyhalofop butyl (CB) @ 80 g/ha, bispyribac sodium (BS) @ 25 g/ha, fenoxaprop-p-ethyl (FPE) @ 60 g/ha, premix of penoxsulam 1.02% (PS) + cyhalofop butyl 5.1% (CB) (6% OD) - commercial formulation @ 150 g/ha, tank mix (TM) of cyhalofop butyl (CB) @ 80 g/ha + carfentrazone ethyl (CE) @ 20 g/ha, TM of bispyribac sodium (BS) @ 25

g/ha + cyhalofop butyl (CB) @ 80 g/ha, TM of bispyribac sodium (BS) @ 25 g/ha + fenoxaprop-p-ethyl (FPE) @ 60 g/ha and stale seedbed (SSB) with TM of glyphosate @ 800 g/ha + oxyfluorfen @ 150 g/ha at 15-20 days after land preparation to knock out weeds followed by (fb) TM of cyhalofop butyl @ 80 g/ha + carfentrazone ethyl @ 20 g/ha at 18 DAS). For season long weedy conditions, an unweeded control was also maintained. Weed management was done as per the treatments.

All the herbicide treatments were applied at 18 DAS, when weeds reached the 3–4 leaf stage. The spray volume used in the study was 500 L/ha, and herbicides were sprayed with a hand operated knapsack sprayer fitted with a flat fan nozzle. In stale seedbed treatment, the fields were drained and weed seeds were allowed to germinate for 15 days, fb chemical weeding with TM of glyphosate 41% SL @ 0.8 kg/ha + oxyfluorfen 23.5% EC @ 0.15 kg/ha at 15-20 days after land preparation. After broadcasting the pre-germinated rice seeds uniformly in puddled field (direct seeded rice), the tank mix combination of cyhalofop butyl @ 80 g/ha + carfentrazone ethyl @ 20 g/ha was sprayed at the 3–4 leaf stage of the weeds and HW was carried out as per the schedule. Weed density and dry weight were measured at 15, 30 and 45 days after treatment application (DATA) using a 0.5 m × 0.5 m quadrat placed randomly in each plot. The weeds were pulled from a randomly selected 0.25 m² area, then dried in an oven at 65°C until reaching a constant weight, with the dry weight recorded in g/m² for each treatment. Weed-control efficiency (WCE) represents the degree of weed reduction achieved by the weed-control treatment and was calculated using the formula provided by Mani *et al.* (1973).

Nutrient removal by weeds at 15, 30, 45 DATA and the content and uptake of major nutrients by the rice crop at harvest were analyzed by standard procedures (Jackson, 1973). The removal of N, P and K by weeds was calculated as the product of the content of these nutrients and the dry weight of weeds sampled and expressed in kg/ha. The nutrient uptake of rice was calculated as the product of nutrient content and the plant dry weight and expressed in kg/ha. For calculating grain yield, grains from each plot, after winnowing and cleaning, were weighed separately and recorded the fresh weight. The grains were dried to 13% moisture content, weighed and expressed in kg/ha. The dry weight of straw from the plot area of each treatment was recorded after sun drying for three consecutive days and was expressed in kg/ha. All the data were analysed through analysis of variance (ANOVA) using standard variance techniques, as suggested by Gomez and Gomez (1984). Weed data were subjected to square root transformation [$\sqrt{(x + 1)}$] before statistical analyses to improve the homogeneity of variance. Treatment means were separated using

the critical difference (CD) at 5% level of significance ($P \leq 0.05$).

RESULTS AND DISCUSSION

Effect of weed management treatments on growth parameters of rice

Growth of the plant is characterized by plant height, number of tillers, number of panicles and dry matter production (DMP). The growth of plants under the treatments that showed phytotoxic symptoms too recovered within one week after application and did not influence their further growth. All herbicidal treatments resulted in taller plants with higher tiller production compared to unweeded control during both the years in DSR (Table 1). Herbicide application reduced weed competition during the early growth phase by providing better access to resources, resulting in an increase in height compared to the unweeded control, where severe weed infestation was observed. The absence of weeding led to a reduction in plant height ranging from 6.61% to 14.36% in wet seeded rice. The significantly lower plant height recorded in the unweeded control during both years might be attributed to the severe competition from weeds, which resulted in poor resource use efficiency and inferior growth attributes. Under direct seeded lowland conditions, Sahu (2016) reported a 14.25% reduction in plant height in the unweeded control. The lower plant height in the early stages of stale seed bed fb chemical weeding may be due to the delay in germination caused by the application of oxyfluorfen, which is adsorbed on to the organic matter in the soil. The strong adsorption of oxyfluorfen in the top soil layers (0-2 cm) and organic matter was earlier reported by Devi *et al.* (2015) and Ameena (2015).

At harvest, the highest number of tillers/m² (336) was recorded in BS @ 0.025 kg/ha + CB @ 0.08 kg/ha during 2018, which was statistically equivalent to BS @ 0.025 kg/ha + FPE @ 0.06 kg/ha, PS + CB (6% OD) @ 0.15 kg/ha, BS @ 0.025 kg/ha and HW twice at 20 and 45 DAS. Unweeded control produced the fewest tillers, 203/m² in 2018 and 197/m² in 2019 (Table 1). Due to severe weed competition, the number of tillers/m² in the unweeded control was reduced by 37.72% compared to HW twice at 20 and 45 DAS. When compared to the unweeded control, herbicide combinations increased tiller production per unit area by 32 to 40%. Tillering capacity reflects the ability of plant to effectively use space, light, and nutrition, and it ultimately contributes to yield.

Higher number of panicles/m² of 304 was recorded in HW twice at 20 and 45 DAS and PS + CB (6% OD) @ 0.15 kg/ha during 2018 and registered an average of 308 and 307 panicles/m², respectively during 2019. This was statistically comparable with BS @ 0.025 kg/ha + FPE @

Table 1. Effect of weed management practices on growth and yield parameters of direct seeded rice

| Treatment | Plant height (cm) at harvesting | | No. of tillers/m ² | | No. of panicles/m ² | | DMP (g/m ²) | |
|---|---------------------------------|------|-------------------------------|------|--------------------------------|------|-------------------------|---------|
| | 2018 | 2019 | 2018 | 2019 | 2018 | 2019 | 2018 | 2019 |
| Cyhalofop butyl @ 0.08 kg/ha | 91 | 99 | 249 | 265 | 224 | 211 | 442.95 | 408.31 |
| Penoxulam + cyhalofop butyl (6% OD) @ 0.15 kg/ha | 97 | 103 | 316 | 328 | 304 | 307 | 857.89 | 892.03 |
| Cyhalofop butyl @ 0.08 kg/ha + carfentrazone ethyl @ 0.02 kg/ha | 99 | 102 | 285 | 303 | 255 | 240 | 643.14 | 751.63 |
| Bispyribac sodium @ 0.025 kg/ha | 100 | 100 | 315 | 321 | 264 | 259 | 701.23 | 727.71 |
| Bispyribac sodium @ 0.025 kg/ha + cyhalofop butyl @ 0.08 kg/ha | 93 | 104 | 336 | 331 | 272 | 276 | 830.42 | 917.77 |
| Bispyribac sodium @ 0.025 kg/ha + fenoxaprop-p-ethyl @ 0.06 kg/ha | 98 | 102 | 319 | 336 | 301 | 304 | 873.68 | 957.33 |
| Fenoxaprop-p-ethyl @ 0.06 kg/ha | 97 | 95 | 289 | 271 | 213 | 228 | 458.25 | 508.29 |
| Stale seedbed/chemical weeding | 97 | 105 | 303 | 323 | 275 | 259 | 719.27 | 786.65 |
| unweeded control | 87 | 89 | 203 | 197 | 100 | 104 | 351.31 | 358.19 |
| Hand weeding twice at 20 and 45 DAS | 96 | 99 | 313 | 331 | 304 | 308 | 946.58 | 1015.60 |
| SEM± | 1.0 | 0.9 | 7.3 | 8.1 | 12.0 | 11.4 | 38.42 | 42.55 |
| CD (P=0.05) | 7.6 | 3.9 | 23.5 | 24.6 | 58.2 | 46.6 | 143.70 | 131.82 |

DMP, Dry matter production; DAS, days after sowing

0.06 kg/ha, SSB fb chemical weeding, BS @ 0.025 kg/ha + CB @ 0.08 kg/ha, BS @ 0.025 kg/ha and CB @ 0.08 kg/ha + CE @ 0.02 kg/ha with the average number of 301, 275, 272, 264 and 255 panicles/m² respectively during 2018. Due to severe weed competition, the number of panicles/m² in the unweeded control was reduced by 66.64% compared to HW twice at 20 and 45 DAS. Herbicide combinations resulted in 59-67% increase in panicle production per unit area as compared to unweeded control.

Weed management practices had a significant influence on the total DMP of crops. Data analysis on pooled DMP revealed that HW twice recorded higher DMP (946.58 and 1015.6 g/m²) and was found to be on par with BS @ 0.025 kg/ha + FPE @ 0.06 kg/ha, PS + CB (6% OD) @ 0.15 kg/ha, and BS @ 0.025 kg/ha + CB @ 0.08 kg/ha during both the years (Table 1). With the exception of CB @ 0.08 kg/ha + CE @ 0.02 kg/ha, application of herbicide combinations resulted in a 33% increase in crop DMP when compared to sole application of herbicides. This could be due to better weed control in these treatments due to less competition for resources like space, light, and nutrients. The DMP of a crop is determined by the ability of plant to photosynthesize, which is influenced by leaf area, nutrient uptake, and favourable environmental conditions (De Datta, 1981). Lower crop DMP in CB @ 0.08 kg/ha + CE @ 0.02 kg/ha could be attributed to increased weed competition and failure to control many weeds as a result of the antagonistic response. Unweeded control had the lowest total DMP (351.31 and 358.19 g/m²), which was comparable to CB at 0.08 kg/ha.

Effect of weed management treatments on yield parameters of rice

Yield in rice is a combination of the number of productive tillers and the filled grains per panicle (Mani *et al.*, 2023). Among the various weed management practices used, HW achieved higher grain yield (5.20 t/ha) and recorded a 60.19% increase in grain yield over the unweeded control in DSR. When compared to the unweeded control, herbicidal treatments increased grain yield by 23.89–58.84%. BS @ 0.025 kg/ha + FPE @ 0.06 kg/ha, PS + CB (6% OD) @ 0.15 kg/ha, and BS @ 0.025 kg/ha + CB @ 0.08 kg/ha produced higher grain yield (5.03, 4.79, and 4.76 t/ha, respectively), which were statistically similar to the hand weeded weed free check (Table 2). Over the unweeded control, these treatments increased grain yield by 58.84, 56.78, and 56.51%, respectively.

Table 2. Effect of weed management practices on grain yield and straw yield of direct seeded rice

| Treatment | Grain yield (t/ha) | | Straw yield (t/ha) | | Pooled yield (t/ha) | |
|---|--------------------|------|--------------------|------|---------------------|-------|
| | 2018 | 2019 | 2018 | 2019 | Grain | Straw |
| Cyhalofop butyl @ 0.08 kg/ha | 3.26 | 2.17 | 4.51 | 3.58 | 2.72 | 4.06 |
| Penoxsulam + cyhalofop butyl (6% OD) @ 0.15 kg/ha | 4.55 | 5.03 | 6.06 | 6.27 | 4.79 | 6.18 |
| Cyhalofop butyl @ 0.08 kg/ha + carfentrazone ethyl @ 0.02 kg/ha | 3.68 | 4.20 | 4.99 | 5.65 | 3.95 | 5.33 |
| Bispyribac sodium @ 0.025 kg/ha | 3.76 | 4.19 | 5.64 | 5.26 | 3.98 | 5.45 |
| Bispyribac sodium @ 0.025 kg/ha + cyhalofop butyl @ 0.08 kg/ha | 4.37 | 5.14 | 5.92 | 6.09 | 4.76 | 6.00 |
| Bispyribac sodium @ 0.025 kg/ha + fenoxaprop-p-ethyl @ 0.06 kg/ha | 4.76 | 5.30 | 6.12 | 6.37 | 5.03 | 6.25 |
| Fenoxaprop-p-ethyl @ 0.06 kg/ha | 3.20 | 3.12 | 4.52 | 4.30 | 3.16 | 4.41 |
| Stale seedbed/b chemical weeding | 4.02 | 4.74 | 5.52 | 5.89 | 4.38 | 5.72 |
| unweeded control | 2.13 | 2.01 | 3.88 | 3.42 | 2.07 | 3.66 |
| Hand weeding twice at 20 and 45 DAS | 4.93 | 5.47 | 6.84 | 6.79 | 5.20 | 6.82 |
| SEm± | 0.17 | 0.23 | 0.17 | 0.22 | 0.19 | 0.18 |
| CD (P=0.05) | 0.88 | 0.91 | 0.84 | 0.76 | 0.70 | 0.53 |

DAS, Days after sowing

The plots treated with CB @ 0.08 kg/ha + CE @ 0.02 kg/ha (3.95 t/ha) had the lowest grain yield among the herbicide combinations, owing to the lower crop DMP. Among the herbicidal treatments, sole application of CB at 0.08 kg/ha and FPE at 0.06 kg/ha resulted in significantly lower grain yield (2.72 and 3.16 t/ha). Weed infestation caused by ineffective control of BLWs and sedges, as well as increased nutrient loss by weeds, resulted in lower crop yield. The unweeded control had the lowest grain and straw yield. Seasonal weed competition in the unweeded control reduced grain yield in DSR by 56.77 in 2018 and 63.13% in 2019, when compared to the treatment with the highest grain yield. Weed infestation was heavy and unabated, resulting in very severe competition and inopportune exploitation of growth factors, which may have resulted in lower yields in unweeded control. Reddy and Ameena (2021b) reported a 59.75 % reduction in grain yield due to weedy check in rainfed lowland wet DSR.

The hand weeded treatment yielded more straw (6.82 t/ha), which was comparable to the herbicide combination treatments BS @ 0.025 kg/ha + FPE @ 0.06 kg/ha (6.25 t/ha), PS + CB (6% OD) @ 0.15 kg/ha (6.18 t/ha), and BS @ 0.025 kg/ha + CB @ 0.08 kg/ha (6.00 t/ha). These treatments increased straw yield by 46.33, 41.44, 40.77, and 39.0%, respectively, when compared to the unweeded control. This could be attributed to increased tiller production as a result of better crop stand and lower competition. The unweeded control generated lower straw yield (3.66 t/ha). The reduced tiller count and poor crop stand in the unweeded control may have resulted in lower straw output.

Herbicide combinations produced higher grain yields

than single herbicide applications, increasing grain yield by 16–28% when compared to BS alone and by 56–59% when compared to unweeded control. Lower crop-weed competition in herbicide combinations compared to sole application during both years may have resulted in higher yield due to improved control of complex weed flora. Rice plants in vigorous stands have an advantage over weeds, resulting in increased growth, allometry, yield components, and, ultimately, yield.

Effect of weed management treatments on nutrient uptake by the crop at harvest

Nutrient uptake of the crop is a function of grain yield, straw yield and its nutrient content. Weed management treatments had a significant impact on total NPK uptake by crop at harvest. Among the herbicide treatments, BS @ 0.025 kg/ha + FPE @ 0.06 kg/ha, PS + CB (6% OD) @ 0.15 kg/ha, and BS @ 0.025 kg/ha + CB @ 0.08 kg/ha had the highest crop nutrient uptake (Table 3). These treatments were statistically comparable to hand weeding twice, which had the highest total nutrient uptake in both 2018 and 2019. This was due to improved crop growth parameters as a result of lower weed count and weed DMP. Higher grain and straw yields were achieved in these treatments due to broad-spectrum weed control, which resulted in less nutrient depletion by weeds, and therefore, greater nutrient uptake of the crop. As a result, the supply of carbohydrates to plant organs increased, which may have resulted in higher DMP. Reduced crop-weed competition at all stages of plant growth provided a favourable growing environment for the crop in the hand weeded plot, which

may have resulted in higher nutrient uptake. Nanjappa and Krishnamurthy (1980) demonstrated an inverse relationship between rice crop nutrient uptake and weed nutrient depletion.

Crop nutrient uptake was the lowest in unweeded control, with 42.39, 3.99, and 38.05 kg N, P, and K/ha recorded, respectively (Table 3). CB at 0.08 kg/ha and FPE at 0.06 kg/ha recorded lower nutrient uptake, both by grains and straw, and were found to be on par with unweeded control during both years. Among tank mix applications, CB @ 0.08 kg/ha + CE @ 0.02 kg/ha had the lowest K uptake, with 90.51 in 2018 and 108.60 kg/ha in 2019. Rigorous weed infestation might have curtailed the nutrient recovery by crops in unweeded control. The application of the herbicide combinations led to minimal weed presence during the critical period and resulted in superior grain yields, increased dry matter production, enhanced crop NPK uptake, and reduced weed NPK removal in direct-seeded rainfed lowland rice (Reddy and Ameena, 2021b).

Weed flora and effect of weed management practices on weed control efficiency

The experimental field was infested with various weeds, including *Leptochloa chinensis*, *Echinochloa colona*, *Isachne miliacea*, *Sphenoclea zeylanica*, *Bergia capensis*, *Monochoria vaginalis*, *Limnocharis flava*, *Ludwigia perennis*, *Alternanthera philoxeroides*, *Lindernia sp.*, *Cyperus iria*, *Cyperus difformis*, *Fimbristylis miliacea* and *Marsilia quadrifolia*. The field was dominated by grass

weeds and the number of broad leaf weeds and sedges were comparatively lower. Tank mix application of BS @ 0.025 kg/ha + FPE @ 0.06 kg/ha registered the least count of grass weeds at all stages and registered 100, 96.89 and 92.97 per cent reduction in weed count over unweeded control at 15, 30 and 45 DATA in DSR (Fig. 2). Amongst the weed management practices, higher weed control efficiency (WCE) of 96.80, 98.56 and 92.84% were recorded in HW twice at 20 and 45 DAS, respectively at 15, 30 and 45 DATA. In DSR, tank mix application of BS @ 0.025 kg/ha + FPE @ 0.06 kg/ha was equally effective as HW twice at 20 and 45 DAS with WCE of 96.55, 98.20 and 89.70%, respectively at 15, 30 and 45 DATA (Fig. 1). This might be possible because of the efficient management of a broad spectrum of weeds by the combined action of herbicides with different mode of action. Combining herbicides with different modes of action effectively controls the weed flora.

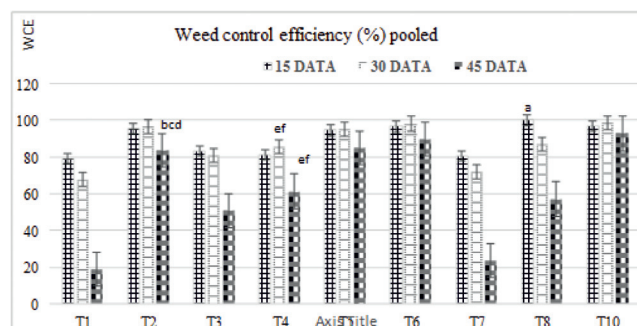


Fig. 1. Effect of weed management practices on pooled weed control efficiency (%)

Table 3. Effect of weed management practices on crop nutrient uptake at harvest

| Treatment | N uptake (kg/ha) | | P uptake (kg/ha) | | K uptake (kg/ha) | |
|---|------------------|--------|------------------|-------|------------------|--------|
| | 2018 | 2019 | 2018 | 2019 | 2018 | 2019 |
| Cyhalofop butyl @ 0.08 kg/ha | 70.22 | 50.21 | 5.55 | 4.78 | 60.84 | 56.62 |
| Penoxsulam + cyhalofop butyl (6% OD) @ 0.15 kg/ha | 140.74 | 109.75 | 13.16 | 12.22 | 147.97 | 139.48 |
| Cyhalofop butyl @ 0.08 kg/ha + carfentrazone ethyl @ 0.02 kg/ha | 107.22 | 82.33 | 9.44 | 9.16 | 90.51 | 108.60 |
| Bispyribac sodium @ 0.025 kg/ha | 113.64 | 68.89 | 9.61 | 8.04 | 110.43 | 107.22 |
| Bispyribac sodium @ 0.025 kg/ha + cyhalofop butyl @ 0.08 kg/ha | 136.68 | 111.17 | 11.83 | 12.54 | 142.42 | 138.04 |
| Bispyribac sodium @ 0.025 kg/ha + fenoxaprop-p-ethyl @ 0.06 kg/ha | 147.54 | 137.31 | 14.25 | 14.11 | 153.52 | 147.84 |
| Fenoxaprop-p-ethyl @ 0.06 kg/ha | 81.44 | 61.34 | 7.66 | 5.67 | 67.00 | 59.21 |
| Stale seedbed fb chemical weeding | 114.88 | 86.84 | 10.25 | 9.79 | 118.10 | 110.76 |
| unweeded control | 50.58 | 34.21 | 4.50 | 3.47 | 39.07 | 37.04 |
| Hand weeding twice at 20 and 45 DAS | 162.68 | 164.62 | 15.33 | 15.64 | 172.44 | 172.26 |
| SEm± | 11.4 | 7.3 | 1.1 | 0.8 | 8.4 | 9.9 |
| CD (P=0.05) | 29.4 | 25.3 | 3.6 | 3.9 | 34.0 | 29.5 |

DAS, Days after sowing

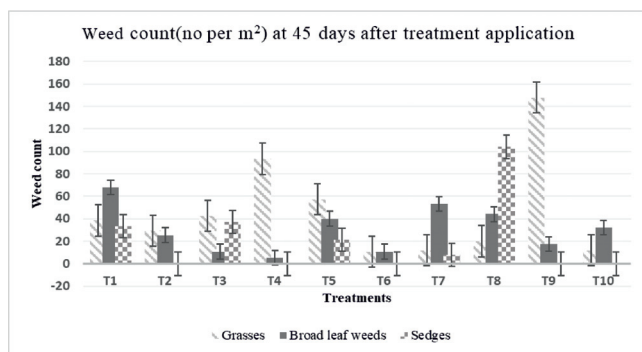


Fig. 2. Effect of weed management practices on weed count at critical period of crop weed competition

Effect of weed management practices on nutrient removal by weeds

Nutrient removal is a function of total weed DMP and nutrient content, and it reflects weed competitiveness, which limits nutrient availability to the crop, instigating yield reduction. Weed management practices statistically influenced nutrient removal by weeds at 15, 30, and 45 DATA. Nutrient removal followed the same pattern as weed DMP. The removal of N, P and K by weeds was noticed more in unweeded control irrespective of the crop growth stage and depleted 27.72, 4.61 and 67.95 kg of N, P and K/ha at 45 DATA (3). This could be attributed to the higher DMP of weeds. Singh *et al.* (1999) observed that throughout the season, weeds depleted 35, 15 and 45 kg/ha of N, P and K respectively, whereas the rice crop in a weed-free environment had an uptake of 60, 26 and 80 kg/ha N, P and K respectively.

Stale seedbed *fb* chemical weeding had the lowest (zero) NPK removal by weeds at 15 DATA during both 2018 and 2019. However, the treatment failed to continue the trend due to increased weed population and higher DMP by weeds, especially BLWs and sedges. The hand weeded treatment, tank mix combination of BS @ 0.025 kg/ha + FPE @ 0.06 kg/ha, BS @ 0.025 kg/ha + CB @ 0.08 kg/ha and ready mix formulation of PS + CB (6% OD) @ 0.15 kg/ha had the lowest nutrient removal values. These treatments correspondingly reduced N, P, and K removal by 92.35, 89.72, 85.22 and 82.31%; 89.15, 88.28, 74.74 and 73.90%; and 95.33, 93.49, 89.85 and 89.23% when compared to unweeded control (Fig. 3). This might be due to the efficient control of a broad spectrum of weeds, which resulted in low weed DMP and hence low nutrient removal. Among the herbicide combinations, CB @ 0.08 kg/ha + CE @ 0.02 kg/ha registered the highest removal of major nutrients, which might be attributed to the inefficiency of the treatment to control *Monochoria vaginalis*.

It can be concluded that the herbicide combinations provided superior growth, nutrient uptake and yield of DSR.

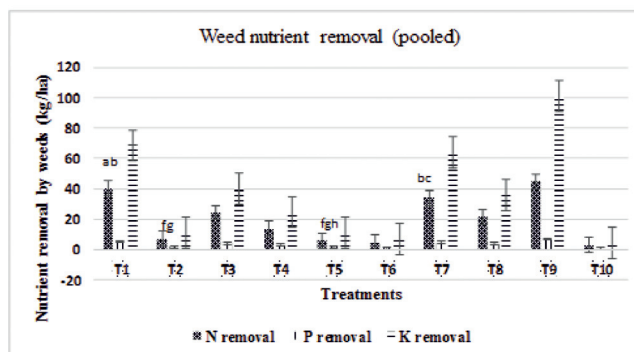


Fig. 3. Effect of weed management practices on nutrient removal (pooled) by weeds at 45 days after treatment application

The tank mix combinations of bispyribac sodium @ 25 g/ha + fenoxaprop-p-ethyl @ 60 g/ha and bispyribac sodium @ 25 g/ha + cyhalofop butyl @ 80 g/ha and the ready mix formulation of penoxsulam + cyhalofop butyl (6% OD) @ 150 g/ha provided more effective management of a broad spectrum of weeds compared to the individual application of bispyribac sodium in DSR.

REFERENCES

- Ameena, M. 2015. Stale seedbed techniques for management of weedy rice (*Oryza sativa f spontanea* L.) in direct seeded rice. *Annals of Agricultural Research* New Series Vol. **36**(4): 410–414.
- Ameena, M., Deb, A., Sethulakshmi, V.S., Sekhar, L., Susha, V.S., Kalyani, M.S.R. and Umkhulzum, F. 2024. Weed Ecology: Insights for Successful Management Strategies: A Review. *Agricultural Reviews*. doi: 10.18805/ag. R-2,661.
- Arya, S.R. and Ameena, M. 2016. Efficacy of new generation herbicides for weed management in semidry rice. *Journal of Tropical Agriculture* **54**(1): 55–59.
- APEDA. 2021. Analytical report of APEDA products. Available online: <http://agriexchange.apeda.gov.in> (accessed on 1 April 2022).
- CGIAR. 2022. Ricepedia [on-line]. Available: <http://ricepedia.org/rice-as-food/theglobal-staple-rice-consumers> (accessed on 21 December 2022).
- Chaudhary, S.K., Marahatta, S. and Chaudhary, M. 2018. Performance of dry direct seeded rice and weeds on Sesbania brown manuring as compared to farmers' practice and chemical control method. *International Journal of Applied Sciences and Biotechnology* **6**(3): 265–269.
- Chauhan, B.S. and Johnson, D.E. 2010. The role of seed ecology in improving weed management strategies in the tropics. *Advances in Agronomy* **105**: 221–262.
- De Datta, S.K. 1981. *Principles and Practices of Rice Production*. 485 p. John Wiley and Sons Inc, New York.
- Devi, D.K.M., Abraham, C.T. and Upasana, C.N. 2015. Leaching behaviour of four herbicides in two soils of Kerala. *Indian Journal of Weed Science* **47**(2): 193–196.
- Duary, B., Mishra, M.M., Dash, R. and Teja, K.C. 2015. Weed management in lowland rice. *Indian Journal of Weed Science* **47**: 224–232.
- GOK. 2022. Farm Guide 2022 [online]. Available: <https://keralaagriculture.gov.in/wpcontent/uploads/2022/01/Farmguide->

- Website-Final.pdf. (accessed on 4 Aug. 2022).
- Gomez, A.K. and Gomez, A.A. 1984. *Statistical Procedures for Agricultural Research* (2nd Ed.). 657 p. John Wiley and Sons, New York.
- Jackson, M.L. 1973. *Soil Chemical Analysis*. 498 p. Prentice Hall of India, New Delhi.
- Kumar, N., Bahadur, R., Yadav, S.K., Singh, S.P., Singh, A., Baheliya, A.K. and Kumar, D. 2024. Productivity and profitability of rice (*Oryza sativa*) influenced by customized fertilizers under rice-wheat cropping system. *Indian Journal of Agronomy* **69** (1): 11–16. DOI: 10.59797/ija.v69i1.5475.
- Mani, V.S., Pandita, M.L. and Gautam, K.C. 1973. Weed killing chemicals in potato cultivation. *Indian Farming* **23**: 7–13.
- Mani, K.M., Ameena, M., Johnson, J.M., Pillai, P.S., John, J. and Beena, R. 2023. Root endophyte *Piriformospora indica* significantly affects mechanisms involved in mitigating drought stress in rice (*Oryza sativa*). *Indian Journal of Agronomy* **68**(3): 324–327 <https://doi.org/10.59797/ija.v68i3.2815>
- Nanjappa, H.V. and Krishnamurthy, K. 1980. Nutrient losses due to weed competition in tall and dwarf varieties of rice. *Indian Journal of Agronomy* **25**: 273–278.
- Reddy, M.S.S.K. and Ameena, M. 2021a. Efficacy of pre- and post-emergence ready-mix herbicides in rainfed lowland wet-seeded rice. *Indian Journal of Weed Science* **53**(1): 88–91
- Reddy, M.S.S.K. and Ameena, M. 2021b. Influence of weed management practices on weed flora, crop yield and nutrient uptake in direct seeded rainfed lowland rice. *Journal of Crop and Weed* **17**(2): 01–08.
- Sahu, P.K. 2016. Yield variation under rice-weed competition in direct seeded lowland condition. M.Sc. (Ag.) Thesis, Orissa University of Agriculture and Technology, Bhubaneswar. Pp. 72.
- Singh, G., Singh, R.K., Singh, V.P., Singh, B.B. and Nayak, R. 1999. Effect of crop-weed competition on yield and nutrient uptake by direct-seeded rice (*Oryza sativa*) in rainfed, lowland situation. *Indian Journal of Agronomy* **44**(4): 722–727.
- Singh, A.K., Tomar, S.K. and Singh, D.P. 2018 b. Bio-efficacy of herbicides and their mixture on weeds and yield of rice (*Oryza sativa*) under rice–wheat cropping system. *Indian Journal of Agronomy*. **63**(2): 145–149.
- Umkhulzum, S.F. and Ameena, M. 2019. Integrated management of rock bulrush (*Schoenoplectus juncooides*) in wet seeded rice. *Journal of Crop and Weed* **15**(3): 139–144.
- Yogananda, S.B., Thimmegowda, P., Shruthi, G.K., 2022. Performance of sequential application of pre and post-emergence herbicides for management of weeds in aerobic rice (*Oryza sativa*). *Indian Journal of Agronomy* **67**(1): 12–19 <https://doi.org/10.59797/ija.v67i1.78>

Optimizing rice (*Oryza sativa*) growth, productivity, profitability and nutrient uptake with coated urea and organic manure in the new alluvial zone of West Bengal

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ABSTRACT

A two-year field experiment was carried out at experimental farm of BCKV, Nadia, West Bengal during *kharif* seasons of 2019–20 and 2020–21 to study the effect of combined application of coated urea and organic manure on performance of rice. The experiment was laid-out in a randomized complete block design with four replications and treatment comprised 5 treatment combinations, such as T₁, control plot (without N); T₂, 100% recommended dose of nitrogen (RDN) through neem-coated urea (NCU); T₃, 75% RDN through NCU + 25% RDN through FYM (farm yard manure); T₄, 100% RDN through polymer sulphur coated urea (PSCU); T₅, 75% RDN through PSCU+25% RDN through FYM. The results showed that 75% RDN through PSCU+25% RDN through FYM resulted in maximum growth attributes, viz. plant height (110.8 cm), maximum number of effective tillers per square meter (416/m²), highest dry-matter accumulation (DMA) (740 g/m²), leaf area index (LAI) (4.47) and crop growth rate (CGR) (6.56 g/m²/day), highest yield components like panicle length (23.5 cm), panicle weight (9.95 g), number of filled grains/panicle (113), test-weight (21.3 g) and maximum grain yield (4.79 t/ha) and straw yield (5.53 t/ha). Similarly, maximum amount of total nutrient uptake by crop (99.7, 40.1 and 208 kg/ha NPK), protein yield (418 kg/ha), gross returns (₹ 71.8 × 10³ /ha), net return (₹ 52 × 10³ /ha) and B: C ratio (2.73) were noticed under T₅ treatment. Therefore, it is advisable to implement a comprehensive nutrient management strategy T₅ (75% RDN through PSCU + 25% RDN through FYM) in rice cultivation. This approach enhances growth, yield, nutrient absorption, and quality, ultimately boosting agricultural productivity, profitability, and sustainability.

Key words: Nutrient acquisition, Organic sources of nutrients, Productivity, Profitability, SCU

Rice (*Oryza sativa* L.) holds significant importance as a cereal crop, both in India and globally. It serves as a staple food grain for over 50% of the global population. India, specifically, boasts the largest rice cultivation area spanning 46.38 million ha, making it the second-largest producer worldwide with a production volume of 130.29 million tonnes (mt). The average productivity in India stands at 2.81 t/ha (GoI, 2022). In the state of West Bengal, rice cultivation covers approximately 5.8 million ha, resulting in a production of 16.6 million tonnes and with a 2.60 t/ha productivity, which is far below the national average. Vari-

ous reasons for low productivity are cultivation of long-duration local cultivars, non-availability of seeds of high-yielding varieties, low solar radiation, high incidence of insect-pests, diseases and weeds, and poor N management (Gounda *et al.*, 2023). Rice is a well-established cereal crop, having high nutrient requirements, particularly for N. Effective N management is a crucial aspect of modern farming practices. The growing global population is driving an increased demand for rice, posing challenges for sustainable rice cultivation practices. One crucial aspect of rice cultivation is optimization of fertilization practices to ensure not only high yields but also environmental sustainability (Shahzad *et al.*, 2019). Traditional fertilizers, such as ordinary urea, have been widely used in rice cultivation. However, the efficiency of N use in cereals, especially heavy feeder crops like rice, is often compromised due to various losses associated with ordinary urea. These losses include NO₃⁻² leaching, NH₃ volatilization, and denitrification, which collectively result in reduced N use efficiency (Sun *et al.*, 2020). One promising approach to mitigate these losses and enhance N-use efficiency is the

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use of coated urea. Coated urea involves encapsulating the nitrogen-containing granules with a protective layer (sulfur or polymers), acts as a barrier, allowing for slow or controlled release of nutrient into the soil (Rehman *et al.*, 2022). This controlled release not only minimizes N losses (leaching, volatilization, and denitrification) but also ensures a sustained and steady supply of N to the plants, optimizing nutrient uptake (Kumar *et al.*, 2024). The slow-release characteristics of coated-urea ensure a sustained supply of nitrogen to plants over an extended period, aligning nutrient availability more closely with the crop's demand. This not only reduces the need for frequent applications but also minimizes the risk of environmental pollution. Additionally, the controlled release allows for better synchronization between nutrient availability and the various growth stages of the rice plant (Samant *et al.*, 2023).

The importance of organic manure in sustainable agriculture has also been widely recognized. Organic manure serves as a rich source of essential nutrients, providing a balanced and diverse array of elements necessary for the healthy growth of rice plants. Unlike synthetic fertilizers that often supply a limited set of nutrients, organic manure contains macronutrients, such as nitrogen, phosphorus, and potassium, as well as micronutrients like zinc, copper, and manganese (Karki *et al.*, 2023). This comprehensive nutrient profile ensures that rice plants receive a holistic and well-rounded diet, reducing the risk of nutrient deficiencies and promoting overall vigor. Organic manure, derived from plant or animal sources, contributes to soil health, enhances microbial activity, and provides a diverse range of nutrients essential for plant growth. Organic manure acts as a microbial stimulant, fostering the growth and activity of beneficial microorganisms in the soil (Pathak *et al.*, 2023). Organic manure stands as a cornerstone for sustainable rice cultivation. Its multifaceted benefits, ranging from nutrient enrichment and soil structure improvement to environmental sustainability, make it an invaluable input in modern agricultural systems. When used in conjunction with synthetic fertilizers like coated urea, organic manure has the potential to synergistically enhance the overall nutrient availability to plants (Rehman *et al.*, 2022). Thus, the combined application of coated-urea and organic manure presents an intriguing avenue for improving the growth, productivity, profitability, and nutrient acquisition of rice. While individual studies have explored the effects of coated urea or organic manure on rice cultivation, there is a noticeable gap in the research regarding their conjoint application. Understanding the interactive dynamics and potential synergies between these two fertilizers is crucial for developing holistic and sustainable fertilization strategies for rice crops. In this context, a field experiment was conducted for two consecutive years to investigate the im-

pact of conjoint application of coated urea and organic manure on growth, productivity, profitability and nutrient acquisition of rice.

MATERIALS AND METHODS

An experiment for two years duration (2019–20 and 2020–21) was conducted at the D-Block farm of BCKV, Nadia, West Bengal. The experimental site is situated at a latitude of 22°98'N and longitude of 84°42'E, with an altitude of 9.50 m above mean sea level (MSL). This region has hot, sub-humid to humid climate. The temperature reached a maximum of 34°C in the month of May and minimum temperature got down to 23°C in the month of October during the crop growing season. The site receives an average annual rainfall of 1440 mm. The soil sample were collected before sowing of *kharif* rice and analyzed therefore. Soil of experimental site was clay loam in texture having bulk density 1.45 Mg/m³ with a neutral soil reaction, low levels of organic carbon (0.49 percent) and available N (205.3 kg/ha), high level of available P (28.8 kg/ha), and medium level of available K (175.5 kg/ha). The experiment was laid-out in a randomized complete block design (RCBD) with four replications and treatments comprised of five treatment combination such as T₁, Control plot (without N); T₂, 100% RDN through neem coated urea (NCU); T₃, 75% RDN through NCU + 25% RDN through FYM (farm yard manure); T₄, 100% RDN through polymer sulphur coated urea (PSCU); T₅, 75% RDN through PSCU + 25% RDN through FYM. The 21 days old rice seedlings of 'Satabdi' variety were transplanted on June 20th, 2019 and June 7th, 2020 respectively, with crop geometry of 20 cm (row to row), and 10 cm (plant to plant spacing). The recommended dose of fertilizers for rice was 150 kg N/ha, 80 kg P/ha, and 60 kg K/ha. The nutrients were supplied through NCU (46% N), PSCU (36% N), SSP (16% P₂O₅) and MOP (60% K₂O) and FYM (0.50% N, 0.25% P₂O₅ and 0.50% K₂O). The prescribed treatments for rice cultivation involved the application of the full amount of farmyard manure (FYM), phosphorus (P), and potassium (K), along with half the dose of nitrogen (N) prior to the transplanting of rice seedlings. The remaining 50% N was administered in line with the recommended treatment schedule in 2-splits during the vegetative stage, and the remaining N split equally—25% at the early tillering stage and 25% at the panicle initiation stage. The harvesting of rice was conducted on October 9, 2019 and October 18, 2020 respectively. The recommended cultivation practices were followed throughout the crop duration. The observations for growth and yield attributes were taken from the standing rice crop. From the 5 tagged plants of rice, plant height was recorded from the ground to the tip of the panicle by meter scale (cm). Leaves of these plants were also used for

calculation of leaf area with the help of leaf area meter (Model LI-COR-3100) and the leaf area index/plant was calculated by using the following formula:

$$\text{LAI} = \frac{\text{Total leaf area/plant (cm}^2\text{)}}{\text{Ground area occupied/plant (cm}^2\text{)}}$$

The culms, leaves, and panicles of the above mentioned collected samples were separated, air-dried in the shade, followed by drying in the hot-air oven at 70 °C till a constant weight was obtained in gram. This dry weight was used for the calculation of mean crop growth rate. The mean crop growth rate was worked out with the following formula, it expressed as g/m²ground area/day.

$$\text{CGR} = \left(\frac{W_2 - W_1}{T_2 - T_1} \right) \left(\frac{1}{S} \right)$$

Where,

W_1 and W_2 are dry weight (g) of plants at time T_1 and T_2 , respectively

$T_2 - T_1$ is the interval of time in days

S is land area (m²) occupied by plants

When the rice reached harvest stage, the tillers in one-meter-square area were counted and expressed as tiller number/m². Five panicles were chosen at random, and the grains from each panicle were counted, averaged, and represented as the total number of grains per panicle. Number of filled grains/panicle from randomly selected panicles were counted. Mean of five panicles was arrived and expressed as number of filled grains/panicle. Thousand grains were drawn randomly from the composite sample of grain yield obtained from each of the net plot area, weighed and expressed as test weight in gram. Manual labour was used to harvest each plot's net area. The product was exposed to sunlight. Plot-wise threshing of the bundles was then done. The grains underwent separate winnowing, followed by 4 days of cleaning and sun-drying. Separate weights were recorded for grain, straw, and chaff. Grain and straw yields have been reported @ 14% moisture content. Samples of grain and straw were prepared for nutritional analysis. Samples were first dried in an oven at 65°C until a constant weight was reached. After that, they were ground in a Willey mill fitted with stainless steel blades. The amount of N (%) in grain and straw was estimated using a modified Kjeldahl technique. Using a UV-VIS spectrophotometer set at 420 nm, the vanadomolybdophosphoric acid yellow colour technique was used to measure the P content of grain and straw. The K concentration in grain and straw was determined by flame photometer. Nutrient uptake was calculated by using the following expression:

N uptake (kg/ha) in grain/straw = [% nutrient in grain/straw × grain/straw yield (kg/ha)]

The N content (%) was multiplied by a conversion factor of 6.25 to estimate the protein content in the grains.

This conversion is derived from the nitrogen content, which typically constitutes 16% of rice protein. Calculating protein yield was done using the following formula:

Protein yield (kg/ha) = Protein content (%) × grain yield (kg/ha)/100

The total value of the output was quantified in monetary terms, and determined using the following formulas:

Gross returns (₹/ha) = Value of the grain (₹/ha) + Value of the straw (₹/ha)

Net returns (₹/ha) = Gross returns (₹/ha) – Total costs (₹/ha)

B: C ratio = Net returns (₹/ha) / Total cost (₹/ha)

The data generated from the characters under study for both the year was analyzed using Fisher's method of ANOVA as described by Gomez and Gomez (1984).

RESULTS AND DISCUSSION

Growth parameters

The results showed that maximum plant height (110.8 cm), DMA (740 g/m²) and LAI (4.47) were recorded in T_5 treatment which was statistically at par with T_3 treatment and significantly better than remaining treatments. The highest value of CGR (6.56 g/m²/day) was noticed under T_5 treatment which was significantly higher than T_1 and stood at par with other treatments. It might be due to slow release of N from coated urea over time owing to its protective coating, providing a sustained supply of nitrogen to the plants. This helps in maintaining a consistent nutrient availability throughout the plant growth cycle, which is essential for optimal growth and development (Rehman *et al.*, 2022).

Yield attributes and yield

A maximum number of tillers/m² (416), panicle length (23.5 cm), panicle weight (9.95g) and 1,000-grain weight (21.3 g) were noticed under T_5 followed by T_3 treatment. The maximum number of filled grains/panicle was observed under T_5 which were statistically at par with T_2 , T_3 , T_4 treatments and significantly higher than T_1 . Similarly, T_5 resulted in significant improvement in grain yield by 103%, straw yield by 90% as compared to other treatments respectively. It might be due to wide range of essential nutrients in organic manure besides nitrogen, such as phosphorus, potassium, and micronutrients. The addition of organic manure alongside coated urea helps in supplying a balanced range of nutrients to the plants, ensuring that their nutritional requirements are adequately met throughout the growing season (Sun *et al.*, 2020). The release pattern of N from the PSCU enhanced the test weight due to larger carbohydrate assimilation and steady nutrient translocation to the panicle from other organs (Sun *et al.*, 2020).

Table 1. Effect of coated urea and organic manure on the growth attributes of rice at different growth stages (pool data of 2019–20 and 2020–21)

| Treatment | Plant height at harvest stage (cm) | DMA at harvest stage (g/m ²) | Leaf area index at maximum growth stage | Crop growth rate at maximum stage (g/m ² /day) | Number of tillers/m ² | Panicle length (cm) | Panicle weight (g) | Number of grains/panicle | 1000-grain weight (g) | Grain yield (t/ha) | Straw yield (t/ha) | Gross returns (× 10 ³ ₹/ha) | Net returns (× 10 ³ ₹/ha) | Benefit: cost ratio |
|----------------|------------------------------------|--|---|---|----------------------------------|---------------------|--------------------|--------------------------|-----------------------|--------------------|--------------------|--|--------------------------------------|---------------------|
| T ₁ | 97.7 | 523.9 | 3.70 | 3.72 | 270.3 | 18.6 | 6.63 | 94.0 | 18.5 | 2.35 | 2.91 | 35.2 | 19.3 | 2.22 |
| T ₂ | 104.6 | 613.3 | 3.96 | 5.31 | 354.9 | 20.2 | 8.12 | 107.0 | 19.4 | 3.92 | 4.91 | 58.7 | 41.5 | 3.41 |
| T ₃ | 109.7 | 733.2 | 4.38 | 6.20 | 377.9 | 22.7 | 9.49 | 112.9 | 20.5 | 4.47 | 5.39 | 66.9 | 48.8 | 3.70 |
| T ₄ | 104.8 | 661.8 | 4.08 | 5.69 | 325.3 | 21.3 | 8.66 | 110.0 | 20.2 | 4.35 | 5.32 | 65.2 | 46.4 | 3.47 |
| T ₅ | 110.8 | 740.0 | 4.47 | 6.56 | 415.9 | 23.5 | 9.95 | 113.0 | 21.3 | 4.79 | 5.53 | 71.8 | 52.5 | 3.73 |
| SEM± | 1.81 | 15.61 | 0.05 | 0.61 | 15.61 | 0.60 | 0.24 | 2.20 | 0.34 | 0.01 | 0.02 | 1.27 | 1.23 | 0.01 |
| CD (P=0.05) | 5.21 | 45.08 | 0.15 | 1.76 | 45.08 | 1.60 | 0.69 | 6.40 | 0.98 | 0.03 | 0.07 | 4.97 | 4.79 | 0.04 |

T₁, [N0 + 100% PK]; T₂, 100% N (NCU) + PK; T₃, [75% NPK (N as NCU) + 25% N by FYM during kharif; T₄, 100% N (PSCU) + PK; T₅, [75% NPK (PSCU) + 25% N by FYM during kharif; DAT, Days after transplanting; NS, Non-Significant at P > 0.05

Nutrient content (%) and uptake (kg/ha)

Different nutrient management practices showed significant effect on nutrient content and uptake by crop (Table 2). Among the different nutrient management practices, treatment T₅ recorded the highest amount of nutrient content in grain (1.40% N, 0.48% P, 2.38% K) and Straw (0.59% N, 0.31% P, 1.70% K) compared to other treatments. This might be due to coated urea and organic manure release nutrients gradually over time. This sustained release pattern ensures a steady supply of nutrients to the plants, minimizing nutrient stress and optimizing nutrient uptake efficiency. As a result, plants can maintain higher nutrient levels in their tissues, promoting healthier growth and development (Shahzad *et al.*, 2019). Similarly, maximum amount of total nutrient uptake by crop (99.7, 40.1 and 208 kg/ha NPK) was found under T₅ treatment. This might be due to enhanced soil fertility and improved nutrient availability by providing organic matter that serves as a reservoir for nutrients. The decomposition of organic matter releases nutrients gradually, making them more readily available to plant roots over an extended period. Coated urea, with its slow-release properties, further extends the availability of nitrogen. This increased availability of nutrients in the root zone stimulates greater nutrient uptake by plants, leading to higher total nutrient uptake (Samant *et al.*, 2023).

Protein content (%) and protein yield (kg/ha)

Among the quality parameters, protein content was not influenced by different nutrient management practices but protein yield was significantly influenced across the study year. The maximum protein yield (418 kg/ha) was recorded under T₅ which was statistically at par with T₃ and significantly higher than other treatments. It might be due to the fact that coated urea provides a slow and sustained release of nitrogen, while organic manure contributes various nutrients including nitrogen, phosphorus, and potassium. A balanced supply of nutrients is essential for the synthesis of proteins in plants. The combination of these fertilizers ensures that plants have access to sufficient nitrogen as well as other essential nutrients needed for protein synthesis, resulting in higher protein content in crops (Rehman *et al.*, 2022). Shahzad *et al.* (2019) stated that coated urea reduces nitrogen losses through leaching and volatilization, making more nitrogen available for plant uptake. Organic manure enhances soil fertility and microbial activity, promoting the efficient uptake and utilization of nitrogen by plants. As a result, the nitrogen supplied by both fertilizers is utilized more effectively for protein synthesis, leading to increased protein content in crops (Karki *et al.*, 2023; Manjappa, 2023).

Table 2. Effect of coated-urea and organic manure on the nutrient uptake and economics of rice at different growth stages (pooled data of 2019–20 and 2020–21)

| Treatment | Nutrient content in grain (%) | | | Nutrient content in straw (%) | | | Nutrient uptake by grain (kg/ha) | | | Nutrient uptake by straw (kg/ha) | | | Total nutrient uptake by crop (kg/ha) | | | Protein content (%) | Protein yield (kg/ha) |
|----------------|-------------------------------|------|------|-------------------------------|------|-------|----------------------------------|------|-------|----------------------------------|------|------|---------------------------------------|------|------|---------------------|-----------------------|
| | N | P | K | N | P | K | N | P | K | N | P | K | N | P | K | | |
| | T ₁ | 1.15 | 0.33 | 2.23 | 0.42 | 0.15 | 1.55 | 27.0 | 7.76 | 52.4 | 12.2 | 4.37 | 45.1 | 39.2 | 12.1 | | |
| T ₂ | 1.26 | 0.39 | 2.28 | 0.49 | 0.21 | 1.61 | 49.4 | 15.3 | 89.4 | 24.1 | 10.3 | 79.1 | 73.5 | 25.6 | 169 | 7.84 | 307 |
| T ₃ | 1.37 | 0.45 | 2.35 | 0.55 | 0.27 | 1.68 | 61.2 | 20.1 | 105.0 | 29.6 | 14.6 | 90.6 | 90.8 | 34.7 | 196 | 8.56 | 383 |
| T ₄ | 1.32 | 0.44 | 2.33 | 0.50 | 0.24 | 1.64 | 57.4 | 19.1 | 101.4 | 26.6 | 12.8 | 87.2 | 84.0 | 31.9 | 189 | 8.25 | 359 |
| T ₅ | 1.40 | 0.48 | 2.38 | 0.59 | 0.31 | 1.70 | 67.1 | 23.0 | 114.0 | 32.6 | 17.1 | 94.0 | 99.7 | 40.1 | 208 | 8.72 | 418 |
| SEM± | 0.01 | 0.00 | 0.01 | 0.00 | 0.00 | 0.002 | 0.19 | 0.10 | 0.16 | 0.14 | 0.10 | 0.23 | 2.22 | 1.10 | 3.98 | 0.03 | 13 |
| CD (P=0.05) | 0.02 | 0.01 | 0.02 | 0.01 | 0.01 | 0.005 | 0.43 | 0.22 | 0.36 | 0.33 | 0.24 | 0.53 | 6.75 | 3.24 | 12.5 | NS | 40 |

T₁, [N0 + 100% PK]; T₂, 100% N (NCU) + PK; T₃, [75% NPK (N as NCU) + 25% N by FYM during kharif; T₄, 100% N (PSCU) + PK; T₅, [75% NPK (PSCU) + 25% N by FYM during kharif; DAT, Days after transplanting; NS, Non-Significant at P > 0.05

Economics

Highest amount of gross returns (₹ 71.8 × 10³/ha), net return (₹ 52 × 10³/ha) and B: C ratio (2.73) were noticed under T₅ as compared to the other treatments but T3 treatment recorded the similar results. The combined application of coated urea and organic manure improves soil fertility, structure, and microbial activity. Healthy soils produce healthier crops with improved resistance to pests and diseases, resulting in higher yields and better crop quality. Higher productivity translates to increased revenues for farmers, offsetting the initial investment in fertilizers (Pathak *et al.*, 2023; Kumar *et al.*, 2024). Coated-urea minimizes nitrogen losses through leaching and volatilization, ensuring that a greater proportion of applied nitrogen is utilized by plants. Organic manure contributes to soil organic matter, enhancing nutrient retention and availability. Together, these fertilizers increase nutrient-use efficiency, allowing farmers to achieve optimal crop yields with lower fertilizer inputs, thus reducing production costs per unit of output (Kaur *et al.*, 2023).

Overall, the study underscores the efficacy of treatment T₅, employing 75% RDN through PSCU combined with 25% RDN through FYM, in maximizing growth attributes, yield components, nutrient uptake, and quality parameters in rice cultivation. T₅ exhibited superior performance across various parameters, including plant height, tiller count, DMA, LAI, CGR, panicle characteristics, grain and straw yields, total nutrient uptake, protein yield, as well as economic indicators such as gross returns, net returns, and Benefit to cost (B: C) ratio. Therefore, adopting a holistic nutrient management approach like T₅ can significantly enhance agricultural productivity, profitability, and sustainability in rice cultivation.

REFERENCES

- GOI, 2022. Agricultural Statistics at a Glance, Ministry of Agriculture & Farmers Welfare Department of Agriculture & Farmers Welfare Economics and Statistics Division, New Delhi
- Gomez, K.A. and Gomez, A.A. 1984. Statistical procedures for agricultural research. 2nd Edition, John Wiley and Sons, New York, Pp. 680.
- Gouda, H.S., Singh, Y.V., Shivay, Y.S. and Manu, S.M. 2023. Effect of enriched composts and establishment methods on crop growth and nutrient concentration of rice (*Oryza sativa*) in trans-Gangetic plains of India. *Indian Journal of Agronomy* 68(2): 126–132.
- Karki, S., Ghosh, M., Chettri, B., Banerjee, B., Bandyopadhyay, S. and Ghosh, T.P.S. 2023. Effect of organic nutrient management on yield, quality, nutrient uptake and economics of aromatic rice (*Oryza sativa*) in hill zone of West Bengal. *Indian Journal of Agronomy* 68(4): 434–438.
- Kaur, P., Saini, K.S., Kaur, K., Singh, T. and Walia, S.S. 2023. Influence of organic amendments and different levels of nitrogen on production potential, economics and energetics of rice (*Oryza sativa*)–wheat (*Triticum aestivum*) cropping system.

- Indian Journal of Agronomy* **68**(3): <https://doi.org/10.59797/ija.v68i3.2801>
- Kumar, N., Bahadur, R., Yadav, S. K., Singh, S.P., Singh, A., Baheliya A.K. and Kumar, D. 2024. Productivity and profitability of rice (*Oryza sativa*) influenced by customized fertilizers under rice-wheat cropping system. *Indian Journal of Agronomy* **69**(1): 11–16. DOI: 10.59797/ija.v69i1.5475.
- Manjappa, K. 2023. Integrated nutrient-management practices effect on productivity of rice (*Oryza sativa*) and soil properties under rainfed lowland rice situation – A long-term study. *Indian Journal of Agronomy* **68**(2): 133–139.
- Pathak, S.O., Dhyani, B.P., Luthra, N., Shahi, U.P. and Shukla, G. 2023. Effect of conjoint application schedules of organic and inorganic sources of nutrients on growth, yield and economics of rice. *Indian Journal of Agronomy* **68**(4): 351–356.
- Rehman, H.U., Malik, G.A., Rao, M.I., Hashim, S., Hussain, S., Irfan, M., Mubeen, K., Ali, M., Alam, M., Ali, M., Haider, I., Shakir, M., Skalicky, M., Ali, A.S., and Alfarraj, S., 2022. Sulphur coated urea improves morphological and yield characteristics of transplanted rice (*Oryza sativa* L.) through enhanced nitrogen uptake. *Journal of King Saud University – Science* **34**(1): 101664.
- Samant, T.K., Garnayak, L.M., Paikaray, R.K. and Mishra, P.J. 2023. Effect of rice-establishment methods and nutrient management on productivity, profitability and soil health under rice (*Oryza sativa*)–groundnut (*Arachis hypogaea*) cropping system. *Indian Journal of Agronomy* **68**(3): 253–259.
- Shahzad, R., Akbar, S., Jamil S., Javed, M.A., Jamil, M.W., Fatima, N. and Iqbal, M.Z. 2019. Polymer coating-based enhancement of fertilizer use efficiency and growth of wheat crop. *International Journal of Bioscience* **14**(2): 562–572.
- Sun, H., Zhou, S., Zhang, J., Zhang, X., Wang, C. 2020. Effects of controlled-release fertilizer on rice grain yield, nitrogen use efficiency and greenhouse gas emissions in a paddy field with straw incorporation. *Field Crops Research* **253**: 107814.

Effect of chemical weed management on growth, yield and economics of drum seeded rice (*Oryza sativa*)

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ABSTRACT

Field experiment was conducted at Periyankunam, Bhuvanagiri Taluk, Cuddalore District during *Kuruvai* 2021 and 2022 to study the effect of different herbicidal weed management on growth, yield and economics of drum seeded rice (*Oryza sativa* L.) variety 'ASD 16'. The experiment was conducted in randomized block design with four replications. The treatments comprised of six weed management practices and are made up of a combination of herbicides (pre-emergence, early-post and post-emergence herbicides) with hand weeding, which was compared with unweeded control and twice hand weeding on 25 and 45 DAS. Application of bensulfuron methyl 0.6% + pretilachlor 6% GR @ 660 g a.i./ha PE *fb* metsulfuron methyl 10% + chlorimuron ethyl 10% WP @ 4 g a.i./ha PoE on 25 DAS *fb* hand weeding on 45 DAS recorded the highest weed control efficiency of 77.55 and 74.23% during *Kuruvai* 2021 and 2022 respectively, growth attributes at 60 DAS viz., plant height (96.82 and 91.79 cm), tillers/m² (367 and 343) and dry matter production (8.01 and 7.78 t/ha), yield attributes like productive tillers/m² (319 and 312), filled grains/panicle (100.64 and 98.42), grain yield (6.19 and 6.11 t/ha) and benefit cost ratio (2.78 and 2.49) during *Kuruvai* 2021 and 2022, respectively over bispyribac sodium 10% SC @ 25 g a.i./ha PoE on 20 DAS *fb* hand weeding on 45 DAS (farmers practice). Hence, it is an efficient weed management practice and an economically feasible method for achieving the maximum growth, yield and economics of drum seeded rice.

Key words: Bensulfuron methyl+pretilachlor, Bispyribac sodium, Drum seeded rice, Yield

Rice (*Oryza sativa* L.) is a staple food crop accounting major share in the total food grain production. In India, rice occupies 43.90 million hectares with a production of 114.45 million tonnes and productivity of 2.61 t/ha (Directorate of Economics and Statistics, 2022). In Tamil Nadu, production and productivity under rice is 2.21 million hectares, 8.07 million tonnes and 3.65 t/ha respectively (DES, 2022). Direct seeded rice refers to the process of growing rice crop by directly sowing seeds in the field rather than by transplanting rice seedlings from the nursery (Yadav *et al.*, 2018). Direct seeded rice required less labour and offers the advantages of quicker and easier planting, tolerance to water deficit which resulted in higher profit besides reduction in carbon footprints (Avasthe *et al.*, 2023 and Yadav *et al.*, 2020). Drum seeding of rice offers many advantages: its light weight, easy to transport, gender-neutral, and addresses labor shortages. It allows for sowing larger areas quickly, ensures uniform spacing, reduces production costs, and boosts returns on investment. However, the con-

trol of weeds in drum seeded rice is a challenging task for effective crop production (Suganya, 2023).

Herbicides are essential for weed management, offering timely, effective, economical, and practical control. Selecting the right herbicide, dose, and method at the right time is crucial for managing weeds and increasing crop yield (Singh *et al.*, 2023). Single herbicide applications are often insufficient due to diverse weed flora and potential herbicide resistance. Therefore, sequential applications of pre- and post-emergence herbicides, combined with hand weeding, or using tank-mix or ready-mix herbicides with different modes of action can control a broad spectrum of weeds and delay resistance (Gogoi and Deka 2023). New-generation herbicide mixes reduce usage rates, minimize crop injury, lower application costs, and lessen residual buildup.

Bensulfuron methyl 0.6% + pretilachlor 6% GR is a new generation pre-emergence herbicide mix that effectively controls perennial and annual weeds in rice. Its granular formulation simplifies application for farmers. Triafamone 20% + ethoxysulfuron 10% WG is a recent herbicide providing excellent weed control, enhancing productivity, and saving time and labor. Weeds mainly observed it by leaves and metabolized to inhibit acetolactate

synthase (ALS), crucial for amino acid biosynthesis. Metsulfuron methyl 10% + chlorimuron ethyl 10% WP offers long-term weed management in rice at low doses and costs. Bispyribac sodium 10% SC, a post-emergence herbicide, effectively controls major grasses, sedges, and broad-leaved weeds by interfering with ALS synthesis. Early weed control in drum-seeded rice through pre-emergence and early post-emergence herbicides prevents weed seed germination and growth, avoiding weed seed bank development. Subsequent weed flushes are managed with post-emergence herbicides and hand weeding. This study focuses on the response of new-generation herbicide combinations on the growth and yield of drum-seeded rice.

MATERIALS AND METHODS

Field experiment was conducted at Periyankunam, Bhuvanagiri taluk, Cuddalore District during *Kuruvai* 2021 and 2022. The field is geographically located at 11°46' North latitude, 79°49' East longitude at an altitude of +5.79 m above mean sea level. The weather of the experimental site is moderately warm with hot summer months. The texture of the experimental field soil is clay loam with pH (6.80), EC (0.18 dS/m), Available nitrogen (236.42), phosphorus (20.63) and potassium (305.30) kg/ha. The experimental design adopted was randomized block design with four replications and a gross plot size of 5×4 m. The experimental period for *Kuruvai* 2021 was 26 May to 12 September 2021 and for *Kuruvai* 2022 was 24 May to 10 September 2022. The treatments comprised of T₁ - unweeded control, T₂ - twice hand weeding on 25 and 45 DAS (days after sowing), T₃ - application of bispyribac sodium 10% SC @ 25 g a.i./ha PoE on 20 DAS fb hand weeding on 45 DAS, T₄ - application of bensulfuron methyl 0.6% + pretilachlor 6% GR @ 660 g a.i./ha PE fb metsulfuron methyl 10% + chlorimuron ethyl 10% WP @ 4 g a.i./ha PoE on 25 DAS, T₅ - application of bensulfuron methyl 0.6% + pretilachlor 6% @ 660 g a.i./ha PE fb metsulfuron methyl 10% + chlorimuron ethyl 10% WP @ 4 g a.i./ha PoE on 25 DAS fb hand weeding on 45 DAS and T₆ - application of triafamone 20% + ethoxysulfuron 10% WG @ 60 g a.i./ha early post-emergence (EPoE) on 12 DAS fb metsulfuron methyl 10% + chlorimuron ethyl 10% WP @ 4 g a.i./ha PoE on 25 DAS fb hand weeding on 45 DAS. The field was ploughed to fine tilth and made to puddled condition. Rice seeds at the rate of 40 kg/ha were soaked in water for 24 hours and stored in gunny bags for 24 hours. The seeding drums were filled with the pre-germinated seeds up to three-fourths of its capacity and sown in the field with a spacing of 20 cm between the rows and 10 cm between the plants of rows. The short duration rice cultivar 'ASD 16' was used as test variety for the experiment.

A fertilizer schedule of 120-17-27 kg N-P-K/ha, respectively was applied. 50% N, full dose of P and 50% K were applied as basal. The remaining 50% each of N were top dressed in two equal splits at active tillering and panicle initiation stages. The balance 50% of potassium was top dressed at panicle initiation stage. The fertilizer materials used were urea, single super phosphate and muriate of potash to supply nitrogen, phosphorus and potassium respectively. As per the treatment schedule, the pre-emergence herbicide, bensulfuron methyl 0.6% + pretilachlor 6% GR (ready mix) @ 660 g a.i./ha was broadcasted. The granular herbicide was applied with dry sand @ 50 kg/ha. The early post emergence herbicide, triafamone 20% + ethoxysulfuron 10% WG (ready mix) @ 60 g a.i./ha was applied on 12 DAS and the post emergence herbicide metsulfuron methyl 10% + chlorimuron ethyl 10% (ready mix) @ 4 g a.i./ha was applied on 25 DAS and bispyribac sodium 10% SC @ 25 g a.i./ha was applied on 20 DAS. The post emergence herbicides are Acetolactate Synthase (ALS) inhibitors and calculated quantity was mixed with water @ 500 L/ha and sprayed through knapsack sprayer fitted with flood jet nozzle. A thin film of water was maintained at the time of both liquid and granular herbicide application. Two hand weeding were done on 25 and 45 DAS. The unweeded control plots were maintained unweeded throughout the cropping period.

Plant height was measured from the base of the plants to the tip of the top most leaf and expressed in cm. In each plot, four quadrates of 0.25 m² each were placed at random and the total tillers were counted and expressed in number/m². Five hills from each plot were selected from outside the net plot of each treatment area and harvested by cutting close to the ground level at 30, 60 DAS and at 90 DAS. These plants were first air dried in shade and then oven dried at 80 ± 5°C for 48 hrs. The oven dry matter production of plant samples was computed and expressed as kg ha⁻¹. At harvest, four quadrates of 0.25 m² area were marked in each plot and the number of productive tillers was counted. After counting the number of productive tillers/m², five sample panicles per treatment plot were separated and grains were counted and used for determining the mean number of filled and unfilled grains/panicle. The grains from net plot were cleaned, sun dried and weighed at 14 per cent moisture content and the grain yield was calculated, computed and expressed in kg/ha. The gross and net income/ha for each treatment was worked out based on the prevailing market rates. The net income was calculated by deducting the cost of cultivation from the gross return. Benefit cost ratio was worked out by dividing the gross return by the cost of cultivation. The data on various characters studied during the course of investigation were statistically analyzed as suggested by Panse and

Sukhatme (1978). Data on weed population and weed dry matter production showed high variation and hence they were subjected to square root transformation $\sqrt{(x + 0.5)}$ and analyzed. Wherever, statistical significance was observed the critical difference at 0.05 level of probability was worked out for comparison and the non-significant comparison was indicated as 'NS'.

RESULTS AND DISCUSSION

Weed characteristics

The predominant weed flora of the experimental field was *Echinochloa colona*, *Echinochloa crus-galli* among grasses, *Cyperus difformis*, *Cyperus rotundus* among sedges, *Eclipta alba* and *Bergia capensis* among broad-leaved weeds. Application of bensulfuron methyl 0.6% + pretilachlor 6% GR @ 660 g a.i./ha PE fb metsulfuron methyl 10% + chlorimuron ethyl 10% WP @ 4 g a.i./ha PoE on 25 DAS fb hand weeding on 45 DAS recorded the lowest grasses (21.78 and 27.12/m²), sedges (15.98 and 19.16/m²), broad-leaved weed population (9.73 and 11.77/m²), total weed population (47.49 and 58.05/m²), weed dry matter production (23.81 and 28.90 g/m²) (Table 1) and the highest weed control efficiency (77.55 and 74.23%) during *Kuruvai* 2021 and 2022 respectively (Fig. 1).

This might be due to pre-emergence application of herbicides will maintain weed free condition up to 15 DAS,

post-emergence herbicides may maintain weed free condition up to 35 DAS and the weeds emerged at the later stage was removed by hand weeding at 45 DAS (Singh *et al.*, 2023). The highest grasses (98.38 and 106.01/m²), sedges (66.30 and 70.28/m²), broad-leaved weed population (46.82 and 48.93/m²), total weed population (211.50 and 225.22/m²), weed dry matter production (138.90 and 146.39 g/m²) was recorded under unweeded control.

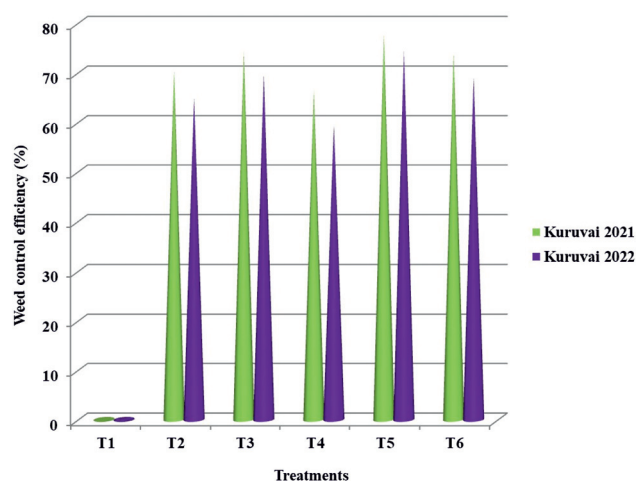


Fig. 1. Effect of chemical weed management on weed control efficiency in drum seeded rice (*Oryza sativa* L.) during *Kuruvai* 2021 and 2022

Table 1. Effect of chemical weed management population and dry weight of weed in drum seeded rice (*Oryza sativa* L.) during *Kuruvai* 2021 and 2022

| Treatment | Total grass weed population (No./m ²) at 60 DAS | | Total sedge population (No./m ²) at 60 DAS | | Total broad-leaved weed population (No./m ²) at 60 DAS | | Total weed population (No./m ²) at 60 DAS | | Total weed dry matter production (g/m ²) at 60 DAS | |
|----------------|---|----------|--|---------|--|---------|---|----------|--|----------|
| | 2021 | 2022 | 2021 | 2022 | 2021 | 2022 | 2021 | 2022 | 2021 | 2022 |
| T ₁ | (9.94) | (106.01) | (66.30) | (70.28) | (46.82) | (48.93) | (211.50) | (225.22) | (138.90) | (146.39) |
| | 98.38 | 10.32 | 8.17 | 8.41 | 6.88 | 7.03 | 14.56 | 15.02 | 11.81 | 12.12 |
| T ₂ | (28.20) | (35.52) | (21.09) | (26.57) | (13.57) | (17.10) | (62.86) | (79.19) | (33.92) | (42.47) |
| | 5.36 | 6.00 | 4.65 | 5.20 | 3.75 | 4.19 | 7.96 | 8.93 | 5.87 | 6.56 |
| T ₃ | (24.90) | (31.29) | (18.13) | (23.28) | (11.43) | (13.73) | (54.46) | (68.30) | (28.27) | (35.30) |
| | 5.04 | 5.64 | 4.32 | 4.88 | 3.45 | 3.77 | 7.41 | 8.29 | 5.36 | 5.98 |
| T ₄ | (31.80) | (41.06) | (23.62) | (30.49) | (15.57) | (20.10) | (70.99) | (91.65) | (39.72) | (52.24) |
| | 5.68 | 6.45 | 4.91 | 5.57 | 4.01 | 4.54 | 8.46 | 9.60 | 6.34 | 7.26 |
| T ₅ | (21.78) | (27.12) | (15.98) | (19.16) | (9.73) | (11.77) | (47.49) | (58.05) | (23.81) | (28.90) |
| | 4.72 | 5.26 | 4.06 | 4.43 | 3.20 | 3.50 | 6.93 | 7.65 | 4.93 | 5.42 |
| T ₆ | (25.10) | (31.80) | (18.47) | (23.40) | (11.59) | (14.68) | (55.16) | (69.89) | (28.67) | (36.33) |
| | 5.06 | 5.68 | 4.36 | 4.89 | 3.48 | 3.90 | 7.46 | 8.39 | 5.40 | 6.07 |
| SEm± | 0.13 | 0.15 | 0.11 | 0.13 | 0.09 | 0.11 | 0.20 | 0.21 | 0.15 | 0.17 |
| C.D (p=0.05) | 0.28 | 0.31 | 0.24 | 0.28 | 0.20 | 0.23 | 0.42 | 0.45 | 0.32 | 0.35 |

T₁- Unweeded control, T₂- Twice hand weeding on 25 and 45 DAS, T₃- Bispyribac sodium 10% SC @ 25 g a.i./ha PoE on 20 DAS fb hand weeding on 45 DAS, T₄- Bensulfuron methyl 0.6% + pretilachlor 6% GR @ 660 g a.i./ha PE fb Metsulfuron methyl 10% + Chlorimuron ethyl 10% WP @ 4 g a.i./ha PoE on 25 DAS, T₅- Bensulfuron methyl 0.6% + Pretilachlor 6% GR @ 660 g a.i./ha PE fb Metsulfuron methyl 10% + Chlorimuron ethyl 10% WP @ 4 g a.i./ha PoE on 25 DAS fb hand weeding on 45 DAS and T₆- Triafamone 20% + Ethoxysulfuron 10% WG @ 60 g a.i./ha EPoE on 12 DAS fb Metsulfuron methyl 10% + Chlorimuron ethyl 10% WP @ 4 g a.i./ha PoE on 25 DAS fb hand weeding on 45 DAS, PE – pre emergence, EPoE – early post emergence, PoE – post emergence, DAS- days after sowing and fb - followed by. *transformed value, **original value.

Grasses were vigorous competitors, exhausting greater portion of the nutrients and were dominant followed by sedges and broad-leaved weeds. Similar findings were also reported by Sangramsingh *et al.* (2022) and Singh *et al.* (2022).

Growth and yield

Application of pre-emergence herbicide *fb* post emergence on 25 DAS *fb* hand weeding on 45 DAS (T_5) recorded the highest growth attributes *viz.*, plant height (96.82 and 91.79 cm), tillers (367 and 343/m²) and dry matter production (8.01 and 7.78 t/ha) during *Kuruvai* 2021 and 2022, respectively (Table 2). The increase in plant height could be due to maximum absorption of plant nutrients from the soil as least density of weeds and increased crop root, shoot growth, increased number of leaves that produced larger amount of photosynthates, resulting in more cell division, cell enlargement and lastly rapid vegetative growth (Verma *et al.*, 2023). Also, effective control of weeds led to better availability of the nutrients and other growth input required for plants. Higher availability of nutrient enabled proper synchronized tillering (Haldar and Thakur 2023). The combination of one herbicide followed by one or two hand weeding effectively decreased the weed density, facilitated the crop to absorb more nutrients from soil and produce more photosynthates through expansion of leaf area which ultimately produce higher dry matter production (Parameswari and Srinivas, 2014).

The lowest growth attributes were recorded under un-weeded control. This might be due to higher weed competition, and lesser input availability to plants thus reduced the plant height to a greater extent (Padhan *et al.*, 2021). The least dry matter accumulation by crop might be due to adverse effect of crop-weed competition as evident from maximum dry matter production by weeds (Yadav *et al.*, 2018). The T_5 also recorded the highest yield attributes *viz.*, productive tillers (319 and 312/m²), filled grains/panicle (100.64 and 98.42) and yield of 6.19 and 6.11 t/ha during *Kuruvai* 2021 and 2022, respectively (Table 2).

Production of more photosynthates via more effective tillers/m² and proper dry matter partitioning (source to sink) resulted in higher grain and straw (Verma *et al.*, 2023). The lowest yield attributes and yield were recorded under unweeded control. These results were in line with the findings of Keerthi De *et al.* (2024). Higher competition by weeds for the available resources resulted in lower growth and yield attributes and finally lower grain and straw yield (Padhan *et al.*, 2021).

Economics

Among the weed management practices tested, application of bensulfuron methyl 0.6% + pretilachlor 6% GR @

Table 2. Chemical weed management effect on growth, yield and economics of drum seeded rice (*Oryza sativa* L.) during *Kuruvai* 2021 and 2022

| Treatment | Growth attributes | | | | Yield attributes and yield | | | | Economics | | | | | | | | | |
|--------------|-----------------------------|-------|-------------------------------------|-------|--|------|--------------------------------------|------|-----------------------|-------|--------------------|------|--|----------|--|--------|--------------------------|------|
| | Plant height at 60 DAS (cm) | | Tillers at 60 DAS (m ²) | | Dry matter production at 60 DAS (t/ha) | | Productive tillers (m ²) | | Filled grains/panicle | | Grain yield (t/ha) | | Gross income (Rs. × 10 ⁶ /ha) | | Net income (Rs. × 10 ⁶ /ha) | | Benefit Cost ratio (BCR) | |
| | 2021 | 2022 | 2021 | 2022 | 2021 | 2022 | 2021 | 2022 | 2021 | 2022 | 2021 | 2022 | 2021 | 2022 | 2021 | 2022 | 2021 | 2022 |
| T_1 | 60.31 | 56.12 | 267 | 254 | 4.67 | 4.51 | 229 | 224 | 74.72 | 74.49 | 3.76 | 3.71 | 71,861 | 64,356 | 34,703 | 27,198 | 1.93 | 1.73 |
| T_2 | 82.60 | 77.95 | 306 | 289 | 6.67 | 6.43 | 288 | 279 | 88.19 | 87.73 | 5.30 | 5.23 | 1,00,745 | 90,414 | 56,837 | 46,506 | 2.29 | 2.06 |
| T_3 | 91.13 | 86.27 | 345 | 328 | 7.38 | 7.19 | 305 | 302 | 96.26 | 93.78 | 5.86 | 5.71 | 1,11,177 | 98,582 | 70,344 | 57,749 | 2.72 | 2.41 |
| T_4 | 75.22 | 70.83 | 285 | 270 | 6.28 | 6.03 | 274 | 266 | 83.67 | 83.15 | 4.97 | 4.86 | 94,523 | 84,096 | 54,515 | 44,088 | 2.36 | 2.10 |
| T_5 | 96.82 | 91.79 | 367 | 343 | 8.01 | 7.78 | 319 | 312 | 100.64 | 98.42 | 6.19 | 6.11 | 1,17,363 | 1,05,347 | 75,105 | 63,089 | 2.78 | 2.49 |
| T_6 | 87.17 | 82.40 | 330 | 317 | 7.05 | 6.90 | 302 | 294 | 92.65 | 92.31 | 5.59 | 5.50 | 1,06,030 | 94,936 | 63,425 | 52,331 | 2.49 | 2.23 |
| S. Em± | 1.98 | 1.96 | 7.57 | 6.40 | 0.19 | 0.16 | 6.39 | 4.18 | 2.16 | 1.86 | 0.15 | 0.12 | 2.61 | 1.84 | 2.37 | 2.67 | — | — |
| C.D (p=0.05) | 3.97 | 3.92 | 15.14 | 12.80 | 0.37 | 0.31 | 12.81 | 8.36 | 4.33 | 3.72 | 0.28 | 0.24 | 5.24 | 3.67 | 4.76 | 5.33 | — | — |

T_1 - Unweeded control, T_2 - Twice hand weeding on 25 and 45 DAS, T_3 - Bispyribac sodium 10% SC @ 25 g a.i./ha PoE on 20 DAS fb hand weeding on 45 DAS, T_4 - Bensulfuron methyl 0.6% + pretilachlor 6% GR @ 660 g a.i./ha PE fb Metsulfuron methyl 10% + Chlorimuron ethyl 10% WP @ 4 g a.i./ha PoE on 25 DAS fb hand weeding on 45 DAS and T_5 - Bensulfuron methyl 0.6% + Pretilachlor 6% GR @ 660 g a.i./ha PE fb Metsulfuron methyl 10% + Chlorimuron ethyl 10% WP @ 4 g a.i./ha PoE on 25 DAS fb hand weeding on 45 DAS and T_6 - Triafamone 20% + Ethoxysulfuron 10% WG @ 60 g a.i./ha EPoE on 12 DAS fb Metsulfuron methyl 10% + Chlorimuron ethyl 10% WP @ 4 g a.i./ha PoE on 25 DAS fb hand weeding on 45 DAS, PE - pre emergence, EPOE - early post emergence, PoE - post emergence, DAS - days after sowing, fb - followed by and Rs. - rupees.

10 kg/ha PE fb metsulfuron methyl 10% + chlorimuron ethyl 10% WP @ 20 g/ha PoE on 25 DAS fb hand weeding on 45 DAS recorded the highest gross income (117.36 Rs.×10³/ha and 105.35 Rs.×10³/ha), net income (75.11 Rs.×10³/ha and 63.09 Rs.×10³/ha) and B:C ratio (2.78 and 2.49) during *Kuruvai* 2021 and 2022, respectively. Timely controls of weeds with timely application of herbicides has increased the yield, save the money in terms of labour cost reduces the cost of cultivation and get the higher gross income and monetary benefit returns. Cultivation of rice under direct seeding using drum seeder significantly lessens the dependency on labour thereby making it cost effective with timely inter-cultural operation. The lowest B:C ratio of 1.93 was recorded under unweeded control. This might be due to the highest weed infestation with the lowest yield.

Thus, it can be concluded that application of bensulfuron methyl 0.6% + pretilachlor 6% GR @ 10 kg/ha PE fb metsulfuron methyl 10% + chlorimuron ethyl 10% WP @ 20 g/ha PoE on 25 DAS fb hand weeding on 45 DAS can be recommended to achieve sustainable rice crop productivity and monetary returns in drum seeded rice. Future research work must be focused on the development of new herbicide combinations with different mode of actions for broad spectrum weed control. Low dosage new generation herbicides may also be developed for effective weed control with minimum environmental hazards.

REFERENCES

- Avasthe, R.K., Devi, S.H., Bhupenanchandra, I., Kumar, A., Chongtham, S.K., Babu, S., Singh, R., Das, A., Gudade, B.A. and Bora, S.S. 2023. Agro-tactics for reducing carbon footprint in agricultural production systems: A review. *Indian Journal of Agronomy* **68**(2): 115-125 <https://doi.org/10.59797/ija.v68i2.332>
- DES. 2022. Agricultural Statistics at a Glance; Directorate of Economics and Statistics, Ministry of Agriculture, Cooperation and Farmers Welfare, Government of India: New Delhi, India, p. 24.
- Gogoi, B. and Deka, J. 2023. Effect of integrated weed-management practices in direct-seeded autumn rice (*Oryza sativa*) on growth, yield and soil microflora. *Indian Journal of Agronomy* 140-146: <https://doi.org/10.59797/ija.v68i2.340>
- Haldar, P. and Thakur, A.K. 2023. Effect of planting geometry and weed-management practices on yield of scented rice (*Oryza sativa*) varieties. *Indian Journal of Agronomy* **68**(4): 430-433: <https://doi.org/10.59797/ija.v68i4.5467>
- Keerthi De, Saravanane, P., Poonguzhalan, R. and Nadaradjan, S. 2024. Brown manuring for improved crop growth, yield and energetics of wet seeded-rice (*Oryza sativa*) in the coastal deltaic eco-system. *Indian Journal of Agronomy* **69**: 87-90.
- Padhan, S.R., Rathore, S.S., Prasad, S.M., Shekhawat, K. and Singh, V.K. 2021. Influence of precision nutrient and weed management on growth and productivity of direct-seeded upland rice (*Oryza sativa*) under Eastern Plateau and Hills Region. *Indian Journal of Agronomy* **66**: 366-369.
- Panse, V.G. and Sukhatme, P.V. 1978. Statistical method for agricultural workers. ICAR, New Delhi. 33rd Edn, p.145.
- Parameswari, Y.S. and Srinivas, A. 2014. Influence of weed management practices on nutrient uptake and productivity of rice under different methods of crop establishment. *Journal of Rice Research* **7**(1&2): 77-86.
- Sangramsingh P.K., Dash, S., Chowdhury, Md. R., Nanda, S.S., Sar, K., Behera, B., Gulati J.M.L. 2022. Effect of integrated application of herbicides and straw mulch on productivity and profitability of rainfed upland rice (*Oryza sativa*). *Indian Journal of Agronomy* **67**(3): 316-319.
- Singh, H., Sandhu, K.S. and Bansal K.K. 2022. Effect of first irrigation scheduling and herbicides on productivity of direct-seeded rice (*Oryza sativa*). *Indian Journal of Agronomy* **67**(1): 93-96. <https://doi.org/10.59797/ija.v67i1.95>
- Singh, S., Ghosh, A., Das, T.K., Dhar, S., Prasad, S.M., Tripathy, S., Verma, G. and Tomar J. 2023. Influence of nitrogen and weed-management practices on crop-growth indices and productivity of dry direct-seeded rice (*Oryza sativa*). *Indian Journal of Agronomy* **68**(1): 89-92 <https://doi.org/10.59797/ija.v68i1.209>
- Suganya, R. 2023. Efficacy of new generation herbicidal combination for weed management in direct seeded rice (*Oryza sativa* L.). Ph.D. (Agri.) Thesis, Department of Agronomy, Annamalai University.
- Verma, B., Bhan, M., Jha, A.K., Agrawal, K.K., Kewat, M.L. and Porwal, M. 2023. Weed management in direct-seeded rice (*Oryza sativa*) in central India. *Indian Journal of Agronomy* **68**(2): 211-214. <https://doi.org/10.59797/ija.v68i2.362>
- Yadav, G.S., Babu, S., Das, A., Mohapatra, K.P., Singh, R., Avasthe, R.K. and Roy, S. 2020. No till and mulching enhance energy use efficiency and reduce carbon footprint of a direct-seeded upland rice production system. *Journal of Cleaner Production* <https://doi.org/10.1016/j.jclepro.122700>
- Yadav, G.S., Das, A., Lal, R., Babu, S., Meena, R.S., Patil, S. B., Saha P. and Datta, M. 2018. Conservation tillage and mulching effects on the adaptive capacity of direct-seeded upland rice (*Oryza sativa* L.) to alleviate weed and moisture stresses in the North Eastern Himalayan Region of India. *Archives of Agronomy and Soil Science*, **64**(9): 1254–1267. <https://doi.org/10.1080/03650340.2018.1423555>



Bio-efficacy of herbicides on weeds in direct-seeded rice in Konkan region of India

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ABSTRACT

Rice cultivation by direct seeding is viewed as both cost and labor-saving practice and becoming popular alternative to transplanting. Weeds are a more serious problem in DSR than in transplanted rice. The field experimental is conducted to evaluate the bio-efficacy of pre and post – emergence herbicides, hand-weeding on weed control, yield components, yield and their economic feasibility for cost effective weed control in direct seeded rice. The experiment was laid out in randomized block design with three replications and seven treatments, viz. Pre-emergence oxadiargyl 80% WP @ 100 g/ha, Pre-emergence oxadiargyl 80% WP @ 100 g/ha fb HW at 30 DAS, oxadiargyl 80% WP (PE) @ 100 g/ha fb Post-emergence bispyribac- Na @ 25 g/ha at 25 DAS, Pre-emergence oxadiargyl 80% WP @ 100 g/ha fb Post-emergence metasulfuron- methyl + chlorimuron – ethyl @ 4 g/ha at 25 DAS, Pre-emergence oxadiargyl 80% WP @ 100 g/ha fb Post-emergence carfentrazone ethyl 40% @ 25 g/ha at 25 DAS. Weed density under weedy check (WC) situation showed that monocot weeds (grasses and sedges) were more pre-dominant wherein grasses and sedges constituted 74.80% and 11.48%, respectively, BLWs 14.20% of total weed density at 60 DAS of crop. Amongst the herbicide treatments, application of Oxadiargyl (PE) @ 100 g/ha fb HW at 30 DAS recorded significantly lowest number of weeds/m², dry weight/m². The highest grain yield (4.02 t/ha) and benefit cost (1.48) were recorded with the pre-emergence application of Oxadiargyl (PE) @ 100 g/ha fb HW at 30 DAS.

Key words: Direct Seeded Rice, Pre- and post-emergence herbicides, Sequential application, Weed density

Rice is an important food crop extensively grown in Konkan. This is widely planted manually by transplanting 20 to 30-days-old seedlings into puddled soil. However, transplanting is becoming increasingly challenging due to unavailability and the high cost of labour and energy, restricted supply of irrigation water, and decline of soil quality (Chauhan, 2012). Konkan region is narrow coastal lowland, gets about 2072-3800 mm annual average rainfall. A major traditional agricultural crop includes rice, millets pulses among the field crops. Rice is an important food crop extensively grown in Konkan, which is widely planted manually by transplanting 20 to 30-days-old seedlings into puddled soil. Rice cultivation by direct-seeding

is viewed as both a cost and labor-saving practice and becoming a popular alternative to transplanting. Weeds are a more serious problem in DSR than in transplanted rice. Weeds should be controlled before they start to compete with rice. Minimize weed seed production and seed recruitment in soil. Weed should be removed or controlled before they set seeds. Ninety per cent loss in grain yield due to weeds in direct-seeded rice was reported by Zahoor *et al.* (2014). However, it is very difficult to control the complex weed flora observed in DSR with application of single pre- or post-emergence herbicide (Mahajan *et al.*, 2013). Thus, effective weed management during early stages of crop growth promises for accomplishment of higher yields. Although manual weeding is effective, it is costly, tedious and time consuming. Due to the morphological similarity, it is often difficult to distinguish some grassy weeds from rice at early stages and sometimes deficit or excessive soil moisture may not permit efficient weeding. The scarcity of man power at critical period of weed infestation is an important hurdle for timely weeding in rice. Relying on

Based on research work carried on during 2019 to 2021 at A.R.S., Repoli.

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herbicides may be the best choice of labour saving technology for timely weed control. On the other side, farmers are also looking forward for the selective herbicides application as pre as well as post-emergence to obtain cost effective management of broad spectrum weeds right from the initial stages compared to hand weeding. However, increased consciousness about the chemical pollution of soil and water has widened the scope for exploring the advantage of low dose herbicides such as oxadiargyl 80% WP (PE) @ 100 g/ha, bispyribac- Na @ 25 g/ha, metsulfuron-methyl + chlorimuron – ethyl @ 4 g/ha, carfentrazone ethyl 40% @ 25 g/ha, which are very effective against wide range of weeds. In cognizance of the above facts, the present investigation was carried out.

MATERIALS AND METHODS

The field experiment was conducted during *Kharif* seasons of 2019, 2020 and 2021, at Agricultural Research Station, Repoli, Raigad, Maharashtra. The soil of the experimental site was medium black soils of Konkan with soil pH was 6.5. It was low in available nitrogen and phosphorus and high in potassium. The experiment was laid-out in a randomized block design with three replications and seven treatments, viz. pre-emergence oxadiargyl 80% WP @ 100 g/ha, pre-emergence oxadiargyl 80% WP @ 100 g/ha *fb* HW at 30 DAS, oxadiargyl 80% WP (PE) @ 100 g/ha *fb* post emergence bispyribac- Na @ 25 g/ha at 25 DAS, pre-emergence oxadiargyl 80% WP @ 100 g/ha *fb* post emergence metasulfuron- methyl + chlorimuron – ethyl @ 4 g/ha at 25 DAS, pre-emergence oxadiargyl 80% WP @ 100 g/ha *fb* post emergence carfentrazone ethyl 40% @ 25 g/ha at 25 DAS. All herbicides were applied in 500 liter of water/ha. These weed control treatments were compared with hand weeding twice at 20, and 40 DAS weed-free check, and weedy-check.

Karjat -5 variety of rice was sown by using line markers at 20 cm row spacing. The crop was fertilized with 100:50:50 kg/ha of N, P₂O₅ and K₂O, respectively. Half dose of N and full dose of P₂O₅ and K₂O were applied at sowing and remaining dose of N was applied in two split doses at tillering and panicle initiation. Herbicides were applied with manually operated knapsack sprayer fitted with flat fan nozzle. In hand weeding, weeds were removed manually. Data on weed density and dry weight were recorded after 20, 40 and 60 days after sowing in each plot in four quadrats (25 × 25 cm²). Weeds were counted in three categories i.e. (grasses, broad leaved weed, and sedges) were removed for recording dry weight of weeds. Weed samples were sun-dried before oven drying at 70 °C until a constant weight was attained. Data on weeds were subjected to square-root transformation ($\sqrt{x} + 0.5$) before statistical analysis. Yield and yield attributes of rice were recorded at

crop harvest. Weed control efficiency was calculated based on weed dry weight.

$$\text{Weed control efficiency (WCE)} = \frac{(\text{WDC} - \text{WDT})}{\text{WDC}} \times 100$$

Where, WDC is the biomass of weeds in weedy plots, WDT is the dry weight of weeds in treated plots.

All the data were analyzed as per the experimental design, and the least significant values at 5% level of significance were calculated to compare treatment means for determining significant differences.

RESULTS AND DISCUSSION

Weed flora

On an average, a weed density of 278/m² was recorded in the weedy-check plot. The major grassy weeds observed in the direct-seeded rice experimental plot were *Echinochloa colona* and *Echinochloa crus-galli* and *Ischane globosa* while, *Cyperus iria* and *Cyperus difformis* were the dominant weeds among sedges and broad-leaved weeds viz., *Eclipta alba* (L.), *Commelina diffusa*. Weed density under weedy-check (WC) situation showed that monocot weeds (grasses and sedges) were more pre-dominant wherein grasses and sedges constituted 74.8% and 11.5%, respectively, however, BLWs 14.2% of total weed density at 60 DAS of crop.

Weed density

Data pertaining to the weed density and dry biomass at 20 and 60 DAS are presented in Table 1. It was observed that all the weed-control treatments reduced the weed density significantly compared to WC. The highest weed density was recorded in WC attributable to uncontrolled weed growth. Weed-free check recorded significantly lower total weed density at 20 and 60 DAS of crop. In case of herbicides treatments, at 20 DAS application of all herbicidal treatments recorded significantly lower weed density as compared to weedy-check treatment. However, application of oxadiargyl (PE) @ 100 g/ha *fb* HW at 30 DAS (T₂) treatment resulted in significantly lower weed density of grassy, sedges and broad-leaf weeds at 60 DAS compared to other weed control treatments. Among the sequential herbicide treatments, application of oxadiargyl (PE) @ 100 g/ha *fb* metsulfuron- methyl + chlorimuron – ethyl @ 4 g/ha at 25DAS (T₄) registered a significantly lower density of grassy, sedges and broadleaf weeds at 60 DAS as compared to other sequential herbicide treatments.

Dry biomass is the way of expressing weed dominance in plot. Biomass provides information about the accumulation of growth. The dry biomass of grasses, broad-leaf and sedges was lower with application of oxadiargyl 80 % WP (PE) @ 100 g/ha *fb* HW at 30DAS (T₂) treatment com-

Table 1. Effect of different herbicides on weed density and dry weight of weeds and weed control efficiency (%) in direct seeded rice

| Treatments | (mean data of 3 years) | | | | | | | | | | | | | | | |
|--|-------------------------------|----------------|--------------|--------------|--------------|--------------|-------------------------------------|----------------|--------------|--------------|-------------|-------------|-------------|--------------|-------|-------|
| | No. of weeds / m ² | | | | | | Total No. of weeds / m ² | | | | | | | | | |
| | Grasses | | BLW | | Sedges | | Grasses | | BLW | | Sedges | | | | | |
| | 20 DAS | 60 DAS | 20 DAS | 60 DAS | 20 DAS | 60 DAS | 20 DAS | 60 DAS | 20 DAS | 60 DAS | 20 DAS | 60 DAS | | | | |
| T ₀ -Oxadiargyl (PE)@ 100 g/ha | 5.28 (27.56) | 6.86 (46.67) | 3.18 (9.78) | 4.26 (17.78) | 3.29 (10.67) | 4.05 (16.00) | 6.96 (48.0) | 8.99 (80.45) | 1.75 (1.83) | 2.73 (7.00) | 1.13 (0.53) | 1.63 (2.17) | 1.88 (3.05) | 3.61 (12.57) | 65.10 | 57.68 |
| T ₁ - Oxadiargyl (PE)@ 100 g/ha/ <i>fb</i> HW at 30DAS | 5.28 (27.56) | 2.65 (6.67) | 3.16 (9.78) | 4.89 (4.89) | 3.25 (10.22) | 2.12 (4.00) | 6.92 (47.56) | 4.01 (15.56) | 1.75 (1.991) | 1.22 (1.00) | 1.12 (0.65) | 1.02 (0.54) | 1.92 (3.21) | 1.72 (2.47) | 65.30 | 91.70 |
| T ₂ - Oxadiargyl (PE)/ <i>fb</i> Bispyribac - Na @ 25 g/ha at 25DAS | 5.14 (26.22) | 4.53 (20.44) | 3.16 (9.78) | 3.51 (12.00) | 3.16 (9.78) | 3.33 (10.67) | 6.76 (45.77) | 6.60 (43.11) | 1.71 (1.91) | 2.01 (3.59) | 1.10 (0.61) | 1.39 (1.45) | 1.91 (3.17) | 2.79 (7.33) | 66.56 | 75.52 |
| T ₃ - Oxadiargyl (PE)/ <i>fb</i> Metsulfuron- methyl+ chlorimuron – ethyl @ 4 g/ha at 25DAS | 5.01 (24.89) | 4.93 (24.00) | 3.12 (9.33) | 3.03 (8.89) | 3.16 (9.78) | 2.90 (8.00) | 6.65 (44.00) | 6.43 (40.89) | 1.68 (2.00) | 1.87 (3.05) | 1.10 (0.65) | 1.25 (1.08) | 1.98 (3.43) | 2.50 (5.83) | 67.85 | 80.37 |
| T ₄ - Oxadiargyl (PE)/ <i>fb</i> carfentozone ethyl 40% @ 25 g/ha at 25DAS | 5.20 (26.67) | 4.90 (24.00) | 3.23 (10.22) | 3.38 (11.11) | 3.14 (9.78) | 3.32 (10.67) | 6.84 (46.67) | 6.75 (45.78) | 1.73 (1.79) | 2.01 (3.58) | 1.10 (0.53) | 1.39 (1.46) | 1.86 (2.97) | 2.75 (7.17) | 65.99 | 75.86 |
| T ₅ - Weed free | 0.71 (0.00) | 0.71 (0.00) | 0.71 (0.00) | 0.71 (0.00) | 0.71 (0.00) | 0.71 (0.00) | 0.71 (0.00) | 0.71 (0.00) | 0.71 (0.00) | 0.71 (0.00) | 0.71 (0.00) | 0.71 (0.00) | 0.71 (0.00) | 0.71 (0.00) | 100.0 | 100.0 |
| T ₆ Weedy check | 9.70 (94.22) | 11.32 (127.78) | 4.85 (23.11) | 5.93 (34.67) | 4.41 (19.11) | 5.41 (28.89) | 11.69 (136.44) | 13.85 (191.33) | 3.03 (3.59) | 4.43 (19.11) | 1.65 (1.26) | 2.10 (3.94) | 2.61 (6.32) | 5.49 (29.70) | 0 | 0 |
| SEM± | 0.25 | 0.27 | 0.13 | 0.12 | 0.16 | 0.12 | 0.27 | 0.26 | 0.07 | 0.10 | 0.03 | 0.05 | 0.05 | 0.10 | - | - |
| CD (P= 0.05) | 0.77 | 0.83 | 0.41 | 0.38 | 0.48 | 0.37 | 0.83 | 0.80 | 0.20 | 0.31 | 0.09 | 0.15 | 0.17 | 0.31 | - | - |

(Figures in parentheses are original values, which were subjected to square root transformation ($\sqrt{x + 0.5}$) before statistical analysis)

pared with weedy-check at 60 DAS and at harvest stages of crop (Table 1). A sequential herbicide treatment, application of oxadiargyl (PE) @ 100 g/ha *fb* metsulfuron- methyl + chlorimuron – ethyl @ 4 g/ha at 25 DAS (T₄) registered significantly lower density of sedges and broad-leaf weeds at 60. This might be due to weeds stop growing after herbicide application and exhibits stunting, inter venial chlorosis and gradual death of the weed so that weed density and dry weight of weeds decreases resulted in reduced competition of crop. Singh *et al.* (2016) who reported initial effectiveness of pre-emergence herbicides, such as pendimethalin and oxadiargyl alone but their performance declined at 45 DAS. Singh *et al.* (2005) emphasized the importance of the sequential application of pendimethalin as pre-emergence and chlorimuron + metsulfuron as post-emergence in realizing reduced grass population. These results conformed with the findings of Yogananda *et al.* (2017), Hemalatha *et al.* (2017), Ramana Murthy *et al.* (2012) and Rajkhowa *et al.* (2005), Sangram Singh *et al.* (2022).

Weed control efficiency

Among herbicidal treatments T₂ (oxadiargyl (PE) @ 100 g/ha *fb* HW at 30 DAS) recorded the maximum weed control efficiency. Among sequential herbicide treatments, application of Oxadiargyl 80% WP (PE) @ 100 g/ha *fb* Metsulfuron- methyl + chlorimuron – ethyl @ 4 g/ha at 25 DAS (T₄) recorded highest weed control efficiency (Table 1). The highest weed control efficiency might be attributed to successive application of 2 herbicides at an interval of 25 days resulting in a reduction in total weed biomass which was comparable to weed free. These results are in agreement with Walia *et al.* (2012) and Dahiphale *et al.* (2015).

Effect of different herbicides on growth, yield attributes and yield of rice

All weed control treatments showed significantly higher values of growth and yield attributes compared to weedy control (Table 2) mainly due to effective suppression of weeds that resulted in improved uptake of inputs like nutrients, light, moisture and other resources by crop. The weed-free check treatment (T₆) recorded significantly superior growth and yield attributes as compared to other treatments including weedy-check. The herbicide treatments increased the plant height (94.44) and yield attributing parameters of rice like number of tillers (481.06 m²), number of effective tillers

Table 2. Effect of different herbicide on, growth, yield attributes and yield of Direct Seeded Rice

| Treatments | Growth, yield attributes and yield of rice | | | | | | | |
|--|--|-------------------------------|----------------------------------|--------------------|--------------------|------------|--------------------------------|----------------------------------|
| | Plant height (cm) | No. of tillers/m ² | Effective tillers/m ² | Grain yield (t/ha) | Straw yield (t/ha) | Weed index | Net return over Input cost (₹) | Benefit-cost ratio on input cost |
| T ₁ : Oxadiargyl 80% WP (PE) @ 100 g/ha | 86.56 | 368.33 | 209.44 | 2.84 | 3.39 | 34.25 | 9518 | 1.17 |
| T ₂ : Oxadiargyl 80% WP (PE) @ 100 g/ha fb HW at 30 DAS | 92.79 | 463.33 | 259.89 | 4.02 | 4.87 | 6.98 | 29974 | 1.48 |
| T ₃ : Oxadiargyl 80% WP (PE) fb Bispyribac - Na @ 25 g/ha at 25DAS | 89.11 | 433.33 | 240.22 | 3.56 | 4.22 | 17.74 | 22403 | 1.38 |
| T ₄ : Oxadiargyl 80% WP (PE) fb Metsulfuron- methyl+ chlorimuron – ethyl @ 4 g/ha at 25 DAS | 94.44 | 481.06 | 269.22 | 4.02 | 4.81 | 7.03 | 29826 | 1.48 |
| T ₅ : Oxadiargyl (PE) fb carfentrozone ethyl 40% @ 25 g/ha at 25 DAS | 89.71 | 447.22 | 248.67 | 3.66 | 4.35 | 15.43 | 25670 | 1.44 |
| T ₆ : Weed free check (2HW at 20 & 40 DAS) | 95.31 | 493.89 | 275.67 | 4.32 | 5.18 | 0.00 | 34215 | 1.52 |
| T ₇ : weedy (control) | 80.57 | 270.56 | 146.78 | 2.05 | 2.45 | 52.66 | -2250 | 0.72 |
| S Em± | 0.95 | 3.72 | 2.81 | 0.07 | 0.08 | - | - | - |
| C.D. at 5 % | 2.92 | 11.45 | 8.67 | 0.21 | 0.26 | - | - | - |

(269.22 m²) were the highest with application of oxadiargyl (PE) @ 100 g/ha fb metsulfuron- methyl + chlorimuron – ethyl @ 4 g/ha at 25 DAS (T₄) which is at par with treatment T₂ where oxadiargyl (PE) @ 100 g/ha fb HW at 30 DAS was applied. This might be attributed to initial vigorous crop growth restricting the growth of weeds that has indirectly boosted the plants to record higher growth parameters and hence improved yield attributes and yield of rice.

Weed-free treatment (T₆) recorded significantly higher grain (4.32 t/ha) and straw yield (5.18 t/ha) of rice than the rest of the weed-control treatments owing to better control of weeds. Among herbicidal and sequential herbicidal treatments, significantly higher grain yield (4.02 t/ha) and straw yield (4.87 t/ha) were recorded with application of oxadiargyl (PE) @ 100 g/ha fb HW at 30DAS (T₂) as compared with other treatment where as it was at par with oxadiargyl 80% WP (PE) @ 100 g/ha fb metsulfuron-methyl + chlorimuron – ethyl @ 4 g/ha at 25 DAS (T₂) was applied. Significantly lower grain yield and straw yields were recorded with weedy-check (2.04 and 2.45 t/ha, respectively). The enhanced yields under these treatments were because of the elimination of weeds which helped in enhancing the availability of nutrients, space, sunlight and water resulting in better growth and development of crop plants. Similarly, among the herbicides a lower weed index (6.98) was recorded in treatment T₂ where in oxadiargyl 80% WP (PE) @ 100 g/ha fb HW at 30 DAS (T₂) followed by treatment T₄ (weed index 7.03) was recorded in which oxadiargyl 80% WP (PE) @ 100 g/ha fb metsulfuron- methyl + chlorimuron – ethyl @ 4 g/ha at 25 DAS was applied. These results conform with the findings of Walia *et al.* (2012) and Mahadkar *et al.* (2015).

Economics

Weed free condition recorded higher net profit on input cost (34215) and benefit cost ratio (1.52) as compared to other remaining treatments (Table 2). Among herbicide treatments, T₂ recorded high net profit (29974) and benefit-cost ratio (1.48) and treatment T₄ recorded net profit (29826) and benefit cost ratio (1.48). Whereas, the lower net returns were recorded in weedy treatment (-2250) as compared with other treatments. Similar results of higher net returns and B:C ratio in direct-seeded rice due to sequential application of herbicides were also reported by Pinjari *et al.* (2016) and Haldar and Thakur (2023).

Based on three years of studies it is concluded that application of oxadiargyl (PE) @ 100 g/ha fb HW at 30 DAS and sequential application of herbicide oxadiargyl (PE) @ 100 g/ha fb Metsulfuron- methyl + chlorimuron – ethyl @ 4 g a.i/ ha at 25 DAS was found to be most effective in weed control as well as higher returns in direct-seeded rice during *kharif* season.

REFERENCES

- Chauhan, B.S. 2012. Weed ecology and weed management strategies for dry-seeded rice in Asia. *Weed Technology* **26**(1): 1–13
- Dahiphale, A.V. Bhagat, S.B., Gangawane, S.B., Shinde, P.S., Govekar Y.R. and Mahadkar, U.V. 2015. Effect of post-emergence herbicide on yield and yield contributing character of transplanted rice in north Konkan region. 25th Asian-Pacific Weed Science Society Conference on “Weed Science for Sustainable Agriculture, Environment and Biodiversity”, Hyderabad, India during 13-16 October, 2015: PP 47.
- Haldar, P., Thakur, A.K. 2023. Effect of planting geometry and weed-management practices on yield of scented rice (*Oryza sativa*) varieties. *Indian Journal of Agronomy* **68**(4): 430–433.

- Hemalatha K., Ramana, A.V., Ramana Murthy K.V. and Jagannadam, J. 2017. Nutrient uptake by rice and weeds as influenced by different weed management practices in dry-seeded rice. *Indian Journal of Weed Science* **49**(3): 287–289.
- Mahadkar, U.V., Dahiphale, A.V., Gangawane, S.B., Shinde P.S. and Kanade. V.M. 2015. Effect of method of sowing and weed control on the performance direct-seeded rice in Konkan region. 25th Asian-Pacific Weed Science Society Conference on “Weed Science for Sustainable Agriculture, Environment and Biodiversity”, Hyderabad, India during 13-16 October, 2015: PP 48.
- Mahajan, G., Chauhan, B.S. and Gill, M.S. 2013. Dry-seeded rice culture in Punjab State of India: Lessons learned from farmers. *Field Crops Research* **144**: 89–99.
- Pinjari SS, Gangawane SB, Mhaskar NV, Chavan SA, Chavan VG and Jagtap DN. 2016. Integrated use of herbicides to enhance yield and economics of direct-seeded rice. *Indian Journal of Weed Science* **48**(3): 279–283.
- Rajkhowa D.J., Barna, I.C., Deka N.C. and Borah, D. 2005. Bioefficacy of oxadiargyl in transplanted rice under rainfed conditions. *Indian Journal of Weed Science* **37**(3 & 4): 258–259.
- Sangrainsingh P.K., Subhprada D., Chowdhury, Md. R., Nanda, S.S., Sar K., Basudev Behera and Gulati, J.M.L. 2022. Effect of integrated application of herbicides and straw mulch on productivity and profitability of rainfed upland rice (*Oryza sativa*) *Indian Journal of Agronomy* **67**(3): 316–319.
- Sen, S., Kaur, R., Das, T.K., Shivay, Y.S. and Sahoo, P.M. 2018. Bioefficacy of sequentially applied herbicides on weed competition and crop performance in dry direct-seeded rice (*Oryza sativa*). *Indian Journal of Agronomy* **63**(2): 230–233.
- Singh, S., Sharma, R.K., Singh, G., Singh, S.S., Singh, U.P., Gill, M.S., Jat, M.L., Sharma, K., Malik, R.K., Joshi, A., Patil, S.G., Ladha, J.K., Gupta, R. 2005. Direct-seeded rice: a Promising resource conserving technology. Rice-Wheat Consortium for Indo-Gangetic Plains. Sept. 2005. NASC Complex, Pusa, New Delhi. p.11–12.
- Singh, V., Jat, M.L., Ganie, Z.A., Chauhan, B.S. and Gupta, R.K. 2016. Herbicide options for effective weed management in dry direct seeded rice under scented rice-wheat rotation of Western Indo-Gangetic Plains. *Crop Protec* **81**: 168–176.
- Walia U S, Walia S S, Sidhu A S and Nayyar S, 2012. Bioefficacy of pre and post-emergence herbicides in direct-seeded rice in central Punjab, *Indian Journal of Weed Science* **44**(1): 30–33.
- Yogananda, S.B., Thimmegowda P. and Shruthi, G.K. 2017. Weed management effect on growth and yield of wet direct-seeded rice in Cauvery command area of Karnataka. *Indian Journal of Weed Science* **49**(3): 219–222.



Impact of fertilizer levels and treated sewage water on heavy metal uptake, growth, agrometeorological indices, and quality of wheat

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ABSTRACT

A field experiment was conducted at Vegetable Research Farm, CCS Haryana Agricultural University, Hisar, Haryana, India to study the agro-physiological, agrometeorological, heavy metals, and quality parameters of wheat under different fertilizer levels and treated sewage water application on sandy loam soil. Among varieties, significantly higher yield attributes viz effective tillers and yield were observed with variety HD 3086 being at par with WH 1105 over HD 2967, WH 1124, and DBW 90. A higher value of agrometeorological indices viz. thermal (2.67 kg/ha/°C day), helio-thermal (0.77 kg/ha degree day hr), and photothermal (0.23 kg/ha degree day hr) use efficiencies were found with variety HD 3086 over other varieties. Among fertilizer levels, significantly higher yield attributes and grain yield were found with 125 % RDF over 75 and 100 % RDF. Significantly higher values of thermal, heliothermal, and photothermal use efficiencies were observed with the application of 125 % RDF over 75 and 100 % RDF. Neither the varieties nor the fertility levels bring any significant variation in normalized difference vegetation index and canopy temperature. However, varying levels of fertilizer did have a substantial impact on chlorophyll content. Similarly, quality parameters viz. hectoliter weight and protein content were not affected significantly by varieties and fertilizer levels. However, sedimentation value was significantly affected by varieties and fertilizer levels. Heavy metal concentration was found in wheat grain, but these were within the permissible limit.

Key words: Heavy metals, Quality, Treated sewage water, Wheat, Yield

Wheat is considered to be a prominent cereal crop cultivated throughout diverse climatic conditions as a source of carbohydrates, vital amino acids, dietary fiber, and minerals. Wheat grain contains more protein than other cereals and provides the characteristic substance “Gluten” which is essential for bakers (Jesal *et al.* 2024). Rapid population growth and urbanization, exhaustive water consumption, and climate change are critical factors for the depletion of freshwater resources. In the present era, the issue of water shortage poses a significant challenge due to the global decline in groundwater resources, and the future, may not be sufficient to meet the growing needs of agriculture and allied sectors (Avasthe *et al.*, 2023). The issue of water scar-

city poses a significant challenge to crop cultivation in arid regions across the globe (Barman *et al.*, 2021). Wastewater in arid and semi-arid areas is a valuable irrigation source and fertilizing material that contributes to economic growth and food security. In situations when freshwater is scarce and the availability of canal water, or high-quality water is limited, major attention has been paid to reusing wastewater for irrigation of various crops. Farmers have explored the use of inferior-quality water as a substitute for good-quality water in crop production (Dotaniya *et al.*, 2022). Untreated or poorly treated wastewater can have harmful effects on soil, plants, and the environment, and be dangerous to humans. Depending upon the source of wastewater from city to city (Rattan *et al.*, 2005), it may contain high concentrations of salts and heavy metals. The high concentrations of salts may adversely affect the physiological processes and growth of wastewater-irrigated plants (Hajihashemi *et al.*, 2020). Disposing of sewage and industrial effluents into natural water sources resulted in soil and water pollution. Hence, proper use of such non-conventional water resources will be environmentally sound disposal practices and water augmentation for

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sustainable agriculture in water-scarce countries with relatively minimum pollution of surface or groundwater. Reusing treated wastewater may nourish crops, prevent water contamination, and lessen the strain on freshwater supplies (Mishra *et al.*, 2023). Crop productivity increases when wastewater is reused depending on soil type, climate, crop, and irrigation practices. Adequate nutrient management is crucial for harvesting the quality yield. Nitrogenous fertilizers play a vital role in yield enhancement, however only 20–50% of the soil-applied nitrogen is recovered by the annual crops (Singh *et al.*, 2024). Hence, it was hypothesized that the conjoint application of nitrogen fertilizers with treated sewage water can improve the growth and quality of wheat varieties grown in semi-arid regions. To achieve the above hypothesis different varieties were screened for physiological parameters and quality under various levels of fertilizers grown under sewage treatment water.

MATERIALS AND METHODS

A field experiment was conducted during the rabi season of 2020–21 and 2021–22 at Vegetable Research Farm, CCS Haryana Agricultural University, Hisar, Haryana, India. The soil of the experimental site was sandy loam in texture, low in organic carbon (3.5 g/kg), and slightly alkaline in reaction (pH 7.6). The available N, P and K were 165, 17, and 295 kg/ha, respectively. The experiment was laid out in split plot design with varieties, viz ‘HD 3086’, ‘HD 2967’, ‘WH 1105’, ‘WH 1124’, and ‘DBW 90’ assisted in main plots and levels of fertilizer, viz. 75, 100, and 125% recommended dose of fertilizer (RDF) in subplots and was replicated thrice. The seedbed was prepared by applying canal water, and treated sewage water was used as an irrigation source for subsequent irrigation. At the sewage-treated plant, CCS Haryana Agricultural University, Hisar campus, the sewage collected from offices and residential areas was treated with the moving bed biological reactor method. The bioreactor that separates the sludge and treated water was designed to treat the sewage with an aerobic attached growth moving bed process. The properties of the treated sewage water sample are given in Table 1.

At the time of sowing half nitrogen and a full dose of phosphorus were applied as per the treatments and the rest of the nitrogen was top-dressed after the first irrigation.

Table 1. Treated sewage water properties

| Irrigation | EC (dS/m) | RSC (meq/l) | Heavy metals (ppm) | | | | | | |
|------------|--------------|----------------|--------------------|------|------|------|----|------|------|
| | | | Co | Pb | Cd | Zn | Cu | Ni | Cr |
| | 1.44 | 1.50 | 0.01 | 0.08 | 0.02 | 0.04 | ND | 0.04 | 0.02 |

ND, Not detected

Single superphosphate and urea were used as the sources of phosphorus and nitrogen, respectively. The crop was sown on 11th November and 4th December in the growing seasons of 2020–21 and 2021–22, respectively using 100 kg seed/ha. Yield attributes and yield were recorded as per standard methods. Soil samples collected after crop harvesting were air-dried and ground to pass through a 2-mm sieve and analyzed for heavy metals (Lindsay and Norvell 1978). Hectolitre mass expressed as kilograms per hectoliter was measured with the hectoliter weight equipment having a standard volume of container/beaker, and the weight of grain was taken on an electronic balance. DS-sedimentation volume is basically a measurement of the sediment volume of a wheat flour suspension after it has been acidified. The sedimentation test is based on the fact that gluten protein absorbs water and swells considerably when treated with SDS lactic acid reagent. The extent of swelling depends upon the quality of gluten protein. It was determined by the method of Axford *et al.* (1979), using sodium-dodecyl sulfate lactic acid reagent (SDSLA). Different agro-meteorological indices and heat-use efficiencies (thermal, heliothermal, and photothermal use efficiency) were calculated as per the standard formula. The nutrient uptake (grain) by crop was worked out by the formula

$$\text{Nutrient uptake (kg/ha)} = \frac{\text{Per cent N content in grain} \times \text{grain yield} \left(\frac{\text{kg}}{\text{ha}}\right)}{100}$$

The recorded data were pooled and analyzed using the online statistical analysis package of OPSTAT (Sheoran *et al.*, 1998).

RESULTS AND DISCUSSION

Agro-physiological parameters: Among varieties, differences were found to be non-significant concerning plant height (Table 2). However, significantly taller plants were observed with the application of 125 percent RDF over lower levels of fertilizer application. The variety HD 3086 produced a significantly higher tiller per square meter than other varieties, however, it was at par with variety WH 1105 with respect to effective tillers. Among fertility levels, the application of 125 percent RDF produced significantly higher effective tillers over 75 and 100 percent RDF. It was found that different varieties did not differ significantly concerning grain number per spike. Different fertility levels differ significantly in respect of grains per spike.

Similarly, the variety HD 3086 produced significantly higher grain yield than other varieties, however, it was at par with variety WH 1105 concerning grain yield (Table 2). Correlation coefficients were also calculated, treatment having a higher effective tiller per plant produced higher grain yield due to a strong and positive correlation between effective tiller per plant and grain yield (Fig. 1). The effects of experimental variables are reflected in the form of yield; hence, yield is the principal criterion for evaluating the efficiency of various treatments. It is a function of effective tillers, the number of grains per spike, and test weight. The use of domestic wastewater has favourably affected the yield and yield attributes of wheat crops due to its continuous application, which might enrich nutrients in topsoil and improve soil properties along with adequate nutrient supply under higher levels of fertilizers that finally result in higher growth parameters such as tillers and leaf area per plant. However, the growth may remain retarded when its supply is suboptimal, which may be ascribed directly to nutritional effects (Kumar *et al.*, 2021). Moreover, nitrogen concentration is indirectly related to one of the basic plant physiological processes, photosynthesis, as 70% of the nitrogen in plant leaves exists in the chloroplast, and most of it is used to synthesize photosynthetic apparatus. Neither the varieties nor the fertility levels bring any significant variation in normalized difference vegetation index and canopy temperature. However, varying levels of fertilizer did have a substantial impact on chlorophyll content. Specifically, the application of 125% RDF resulted in significantly higher chlorophyll content compared to the application of 75% RDF. No significant differences were observed in terms of chlorophyll content between the 100 and 125% RDF levels (Table 2).

Nutrient and heavy metal uptake: Heavy metal concentration was reported in wheat grain and increased with in-

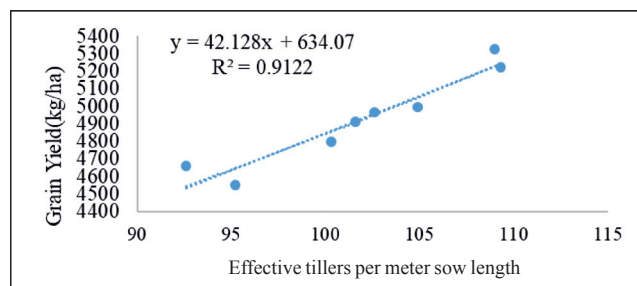


Fig. 1. Relation between effective tillers and grain yield

creasing levels of fertilizer but these were within the permissible limit (Fig. 3a and b). Using treated wastewater for irrigation over an extended period may bring health concerns to people since it can build up and come into touch with food directly (Kim *et al.*, 2015). Heavy metals tend to assemble in the surface soil due to their limited solubility and plant uptake. The mobility and availability of heavy metals depend on plant types, soil characteristics, temperature, pH, humidity, and organic matter content. Heavy metal uptake is lower in food crops and roots, whereas higher in leafy vegetables (Qureshi *et al.*, 2016). The findings indicated that the application of fertilizer had a considerable impact on the uptake of nutrients N, P₂O₅, and K₂O. The administration of 125 percent RDF resulted in a notably greater uptake of nutrients compared to the application of 75 and 100 percent RDF (Table 3). Increased mineral nutrient absorption or enhanced NPK uptake by wheat grain was due to improved vegetative growth under the congenial environment of adequate moisture and nutrients. Treated sewage water may be high in organic matter and contain significant amounts of essential plant nutrients (Meena *et al.*, 2016). Accordingly, continuous irrigation with treated sewage wastewater is projected to increase the nutrient pool in soils and plants significantly. When soil is

Table 2. Agro-physiological parameters of wheat as influenced by fertilizer levels under-treated sewage water application (2-year mean)

| Treatment | Agronomical parameters | | | | Physiological Parameters | | |
|--------------------------|------------------------|----------------------------------|--------------|---------------------|--------------------------|----------------------------|-------------------------|
| | Plant height (cm) | Effective tillers/m ² | Grains/spike | Grain yield (kg/ha) | NDVI | Chlorophyll content (SPAD) | Canopy Temperature (°C) |
| <i>Wheat varieties</i> | | | | | | | |
| 'HD 3086' | 97.8 | 437.3 | 44.7 | 5222 | 0.73 | 47.5 | 27.3 |
| 'HD 2967' | 99.5 | 401.3 | 42.1 | 4798 | 0.73 | 48.6 | 27.2 |
| 'WH 1105' | 96.4 | 419.7 | 42.8 | 4997 | 0.72 | 47.6 | 27.1 |
| 'WH 1124' | 99.4 | 370.4 | 45.3 | 4661 | 0.74 | 46.5 | 27.6 |
| 'DBW 90' | 97.9 | 410.4 | 43.0 | 4964 | 0.73 | 48.5 | 26.7 |
| CD (P=0.05) | NS | 25.4 | NS | 262 | NS | 1.4 | NS |
| <i>Fertilizer levels</i> | | | | | | | |
| 75% RDF | 95.7 | 380.9 | 41.3 | 4549 | 0.73 | 46.7 | 27.0 |
| 100% RDF | 98.2 | 406.4 | 43.2 | 4910 | 0.72 | 47.9 | 27.3 |
| 125% RDF | 100.8 | 436.2 | 46.3 | 5327 | 0.73 | 48.6 | 27.2 |
| CD (P=0.05) | 2.3 | 10.9 | 1.2 | 181 | NS | 0.9 | NS |

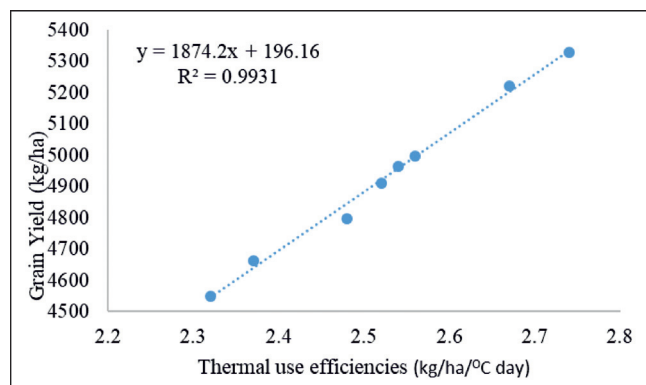


Fig. 2(a). Relationship between thermal use efficiency and grain yield

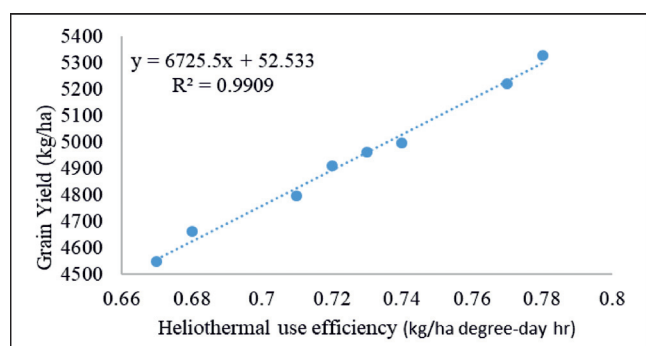


Fig. 2(b). Relationship between helio-thermal use efficiency and grain yield

irrigated with wastewater rather than freshwater, the hydrolysis activity is greater, which is connected to the microorganisms' breakdown of dissolved organic carbon. Increased activity may result in better soil fertility because 90% of soil processes are facilitated by soil bacteria (Furtak and Gajda, 2017). A significant increase in NPK

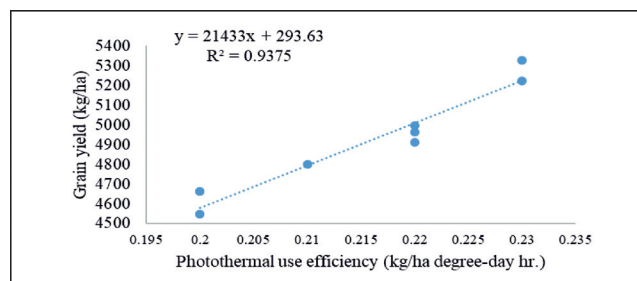


Fig. 2(c). Relationship between photo-thermal use efficiency and grain yield

content and uptake in wheat and barley crops with the use of municipal-treated wastewater was observed by Lal *et al.* (2015).

Quality parameters: The smaller the grain size, the more the number of grains taken per unit volume and more the hectoliter weight. Neither the varieties nor the fertility levels bring any significant variation in the quality parameters viz. hectoliter weight and protein content (Table 3). However, sedimentation value was significantly affected by varieties and fertilizer levels. Higher value of protein content might be due to higher nitrogen availability in soil which in turn increased the nitrogen uptake and ultimately improved the protein (Singh *et al.*, 2024). The sedimentation value of variety 'HD 3086' was found to be significantly greater compared to varieties 'WH 1124' and 'DBW 90'. However, there was no significant difference in sedimentation value between variety 'HD 3086' and varieties 'HD 2967' and 'WH1105'. The application of 125% RDF resulted in a significantly greater value compared to the application of 75% RDF. However, no significant difference was observed between the application of 125 and 100% RDF and between the application of 75 and

Table 3. Nutrient uptake, quality parameters, and agrometeorological indices of wheat as influenced by fertilizer levels under-treated sewage water application (2-year mean)

| Treatment | Nutrient uptake (kg/ha) | | | Quality parameters | | | Agrometeorological indices | | |
|--------------------------|-------------------------|------|------|---------------------------|--------------------------|-----------|----------------------------|----------------------------|----------------------------|
| | N | P | K | Hectolitre weight (kg/hl) | Sedimentation value (ml) | Protein % | TUE (kg/ha/°C day) | HTUE (kg/ha degree-day hr) | PTUE (kg/ha degree-day hr) |
| <i>Wheat varieties</i> | | | | | | | | | |
| 'HD 3086' | 83.6 | 18.0 | 19.5 | 77.6 | 37.8 | 13.3 | 2.67 | 0.77 | 0.23 |
| 'HD 2967' | 75.6 | 18.7 | 19.1 | 77.3 | 37.3 | 13.2 | 2.48 | 0.71 | 0.21 |
| WH 1105' | 84.3 | 21.3 | 20.0 | 78.0 | 37.6 | 13.4 | 2.56 | 0.74 | 0.22 |
| 'WH 1124' | 70.8 | 18.2 | 18.9 | 78.2 | 35.6 | 13.2 | 2.37 | 0.68 | 0.20 |
| 'DBW 90' | 79.8 | 19.0 | 19.6 | 75.1 | 35.5 | 13.1 | 2.54 | 0.73 | 0.22 |
| CD (P=0.05) | 8.1 | 2.1 | NS | NS | 1.8 | NS | 0.14 | 0.03 | 0.01 |
| <i>Fertilizer levels</i> | | | | | | | | | |
| 75% RDF | 65.3 | 16.0 | 16.0 | 76.7 | 35.6 | 13.1 | 2.32 | 0.67 | 0.20 |
| 100% RDF | 78.8 | 19.1 | 18.7 | 76.3 | 36.6 | 13.2 | 2.52 | 0.72 | 0.22 |
| 125% RDF | 92.5 | 22.1 | 23.6 | 78.7 | 38.1 | 13.5 | 2.74 | 0.78 | 0.23 |
| CD (P=0.05) | 6.7 | 1.1 | 1.5 | NS | 1.9 | NS | 0.10 | 0.02 | 0.01 |

100% RDF (Table 3). The sedimentation value is well known for measuring the quantity and quality of wheat gluten (Song *et al.*, 2020), which also provides an idea about the protein content and bread-making quality of wheat grain (Bulut *et al.*, 2013). Treated sewage irrigation water has a high amount of nitrogen in it. However, nitrogen takes part in many metabolic activities and is a major component of amino acids. Hence, the application of treated sewage water improved the quality of wheat grain in terms of protein content, sedimentation value, and hectolitre weight by affecting the flour P concentration and flour and plant tissue N concentrations.

Agro-meteorological efficiencies: Among varieties, higher values of agrometeorological indices viz. thermal (TUE), heliothermal (HTUE), and photothermal use efficiencies (PTUE) were found with variety HD 3086 over other varieties. Among fertilizer levels, significantly higher thermal, heliothermal, and photothermal use efficiency values were observed with 125 % RDF over 75 and 100 % RDF (Table 3). This might be due to more utilization of degree day as a heat unit concept of crop and to be greater vegetative growth (dry matter accumulation and yield) caused, by increasing fertility levels (Kumar *et al.*, 2021). A strong and positive correlation was found between yield and agrometeorological efficiencies (Fig. 2a, b & c).

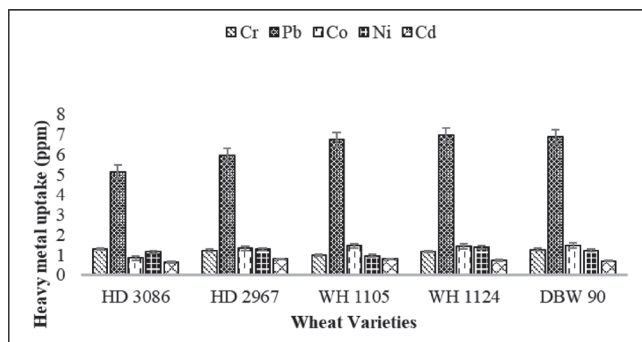


Fig. 3(a). Heavy metals uptake as influenced by wheat varieties

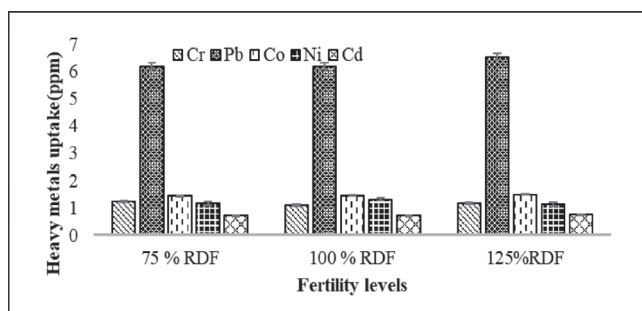


Fig. 3(b). Heavy metals uptake as influenced by fertility levels

The study concluded that variety 'HD 3086' was superior over other varieties concerning growth, productivity, and agrometeorological efficiencies when grown with a

higher dose of fertilizer under-treated sewage water application under a semi-arid environment.

REFERENCES

- Avasthe, R.K., Devi, S.H., Bhupenchandra, I., Kumar, A., Chongtham, S.K., Babu, S., Singh, R., Das, A., Gudade, B.A. and Bora, S.S. 2023. Agro-tactics for reducing carbon footprint in agricultural production systems: A review). *Indian Journal of Agronomy* **68**(2): 115–125. <https://doi.org/10.59797/ija.v68i2.332>
- Axford, D.W.E., Mc-Dermott, E.E. and Redman, D.G. 1979. Note on SDS-sedimentation test and bread making quality. Comparison with pelshenke and zeleny-tests. *Cereal Chemistry* **56**: 582–584.
- Barman, A., Singh, V.K., Rathore, S.S, Babu, S. and Sharma, V.K. 2021. Deficit-irrigation management and agri-horti system compatibility using drip for enhancing water-use efficiency and profitability in Indian mustard (*Brassica juncea*). *Indian Journal of Agronomy* **66**(3): 378–381. <https://doi.org/10.59797/ija.v66i3.2864>
- Bulut, S., Ozturk, A., Karaoglu, M.M. and Yildiz, N. 2013. Effects of organic manures and non-chemical weed control on wheat. II. Grain quality. *Turkish Journal of Agriculture and Forestry* **37**(3): 271–280.
- Dhillon B.S. and Sohu, V.S. 2024. Climate change shocks and crop production: The foodgrain bowl of India. *Indian Journal of Agronomy* **69**(1): 1–10. DOI: 10.59797/ija.v69i1.5474
- Dotaniya M. L., Meena V. D., Saha J. K., Dotaniya C. K., Mahmoud Alaa El Din, Meena B. L., Meena M. D., Sanwal R. C., Meena Ram Swaroop, Doutaniya R. K., Solanki Praveen, Lata Manju and Rai P.K. 2022. Reuse of poor-quality water for sustainable crop production in the changing scenario of climate. *Environment, Development and Sustainability* <https://doi.org/10.1007/s10668-022-02365-9>
- Furtak, K. and Gajda, A.M. 2017. Activity of dehydrogenases as an indicator of soil environment quality. *Polish Journal of Soil Science* **50**(1). <https://doi.org/10.17951/pjss/2017.50.1.33>
- Hajhashemi S., Mbarki S., Skalicky M., Noedoost F, Raeisi M and Brestic M. 2020. Effect of wastewater irrigation on photosynthesis, growth, and anatomical features of two wheat cultivars (*Triticum aestivum*). *Water* **12**, 607; doi:10.3390/w12020607
- Jesal, P.J., Chaudhari, P.P. and Patel, P.H. 2024. Preceding *kharij* crops and fertilizers influence on growth, yield and nutrient requirement of succeeding wheat (*Triticum aestivum*). *Indian Journal of Agronomy* **69**(1): 38–43.
- Kumar, P., Sharma, S.K., Kumar A. and Thakral, S.K. 2021. Agro-meteorological indices and productivity of chickpea (*Cicer arietinum*) under dryland condition as influenced by seed priming and chemi-biofertilizers. *Indian Journal of Agronomy* **66**(1): 46–50.
- Lal, K., Minhas, P.S. and Yadav, R.K. 2015. Long-term impact of wastewater irrigation and nutrient rates II. Nutrient balance, nitrate leaching and soil properties under peri-urban cropping systems. *Agricultural Water Management* **156**: 110–117.
- Lindsay, W.L. and Norvell, W.A. 1978. Development of a DTPA soil test for zinc, iron, manganese and copper. *Soil Science Society of America Journal* **42**: 421–428.
- Meena, R., Datta, S.P., Golui, D., Dwivedi, B.S. and Meena, M.C.

2016. Long-term impact of sewage irrigation on soil properties and assessing risk in relation to transfer of metals to human food chain. *Environmental Science and Pollution Research* **23**(14): 14,269–14,283.
- Mishra S., Kumar R. and Kumar M. 2023. Use of treated sewage or wastewater as an irrigation water for agricultural purposes- Environmental, health, and economic impacts. *Total Environment Research Themes* <https://doi.org/10.1016/j.totert.2023.100051>
- Qureshi, A.S., Hussain, M.I., Ismail, S., Khan, Q.M. 2016. Evaluating heavy metal accumulation and potential health risks in vegetables irrigated with treated wastewater. *Chemosphere* **163**: 54–61. <https://doi.org/10.1016/j.chemosphere.2016.07.073>.
- Rajanna, G.A., Dass, A., Singh, V.K., Choudhary, A.K., Paramesh, V., Babu, S., Upadhyay, P.K., Sannagoudar, M.S., Ajay, B.C. and Reddy, K.V. 2023. Energy and carbon budgeting in a soybean–wheat system in different tillage, irrigation and fertilizer management practices in South-Asian semi-arid agroecology. *European Journal of Agronomy* **148**: 126,877. <https://doi.org/10.1016/j.eja.2023.126877>
- Rattan R.K., Datta S.P., Chhonkar P.K., Suribabu K., Singh A.K. 2005. Long-term impact of irrigation with sewage effluents on heavy metal content in soils, crops and groundwater—a case study. *Agriculture, Ecosystems and Environment* **109**: 310–322.
- Sheoran, O.P., Tonk, D.S., Kaushik, L.S., Hasija, R.C., Pannu, R.S. 1998. Statistical Software Package for Agricultural Research Workers. Recent advances in information theory, statistics and computer application by DS Hooda and RC Hasija, Department of mathematics statistics, CCS HAU, Hisar.
- Singh, P., Chitale, S. and Lakpale, R. 2024. Maximizing wheat (*Triticum aestivum*) productivity through variable nutrient management practices. *Indian Journal of Agronomy* **69**(2): 130–136.
- Singh, S., Singh V. and Kumar M. 2024. Effect of zinc and boron on grain quality of wheat (*Triticum aestivum*) in north-western plain zone of India. *Indian Journal of Agronomy* **69**(1): 44–47.
- Song, L Li, L, Zhao, L., Liu, Z and Li X. 2020. Effects of nitrogen application in the wheat booting stage on glutenin polymerization and structural–thermal properties of gluten with variations in HMW-GS at the Glu-D1 Locus. *Foods* **9**(3): 353.

Effect of zinc management on yield, nutrient content, and acquisition of zero-tilled wheat (*Triticum aestivum*)

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ABSTRACT

A field experiment was conducted during the winter (*rabi*) season 2018–19 and 2019–20 at Khalsa College, Amritsar, Punjab to find out the effect of soil and foliar application of $\text{ZnSO}_4 \cdot 7\text{H}_2\text{O}$ on zero till wheat. The experiment was conducted in a randomized complete block design with three replications. Treatments were control (noZn), soil application of 12.5, 25, 37.5, 50 kg/ha zinc sulfate heptahydrate ($\text{ZnSO}_4 \cdot 7\text{H}_2\text{O}$), and foliar application of 0.5% Zn as one spray at heading initiation (5% ear emergence), one spray at 100% heading (complete ear emergence) and two sprays at heading initiation and 100% heading with a recommended dose of fertilizer. Results showed that the soil application of 50 kg Zn/ha with two foliar sprays of 0.5% zinc sulfate heptahydrate at heading initiation and 100% heading produced the highest yield attributes and grain yield of wheat. Application of 50 kg Zn/ha with two foliar sprays of 0.5 % Zn at heading initiation and 100% heading registered ~25% higher grain yield over control. Grain Zn content (41.77ppm) percent increase was 33.9 with 50 kg Zn/ha with two foliar sprays of 0.5 % zinc at heading initiation and 100% heading over control (31.20 ppm). Likewise, application of 50 kg Zn/ha with two foliar sprays of 0.5 % Zn at heading initiation and 100% heading recorded the highest net returns among the Zn treatments. Overall, soil application of 50 kg Zn/ha with two foliar sprays of 0.5 % zinc at heading initiation and 100% heading improved the yield, uptake, and profitability of zero-tilled wheat in zinc-deficient soils.

Key words: Grain yield, Soil and foliar spray, Zero till wheat, Zinc

Wheat (*Triticum aestivum* L.) is the principal source of food for millions of people particularly in developing countries. However, wheat grains are often lacking in certain micronutrients like zinc (Zn), boron (B), and iron (Fe) which are essential for human health (Nadeem *et al.*, 2019). Wheat plays a crucial role in providing essential micronutrients and contributing to 70% of daily calories in third-world countries. (Cakmak, 2008). Among micronutrients, deficiency of Zn is most wide spread in wheat-growing regions. Worldwide, about 50% of cultivated soils are found deficient in bioavailable Zn (Groote *et al.*, 2021). More than two billion people worldwide are suffering from several disorders due to a deficiency of micro nutrients. However, about 1.25 billion population is at risk of Zn inadequacy (Kumssa *et al.*, 2015). The continuous cultivation of nutrients exhaustive cereal crops has endangered the productivity and sustainability of the cereal-based system due to soil degradation, excessive mineral extraction, micronutrient deficiencies, and higher production costs (Yadav *et al.*, 2024; Zulfiqar *et al.*, 2020). Applying one

nutrient can impact the absorption of others by creating different compounds in soil and plants (Yadav *et al.*, 2016). Compared to other cereals, wheat cultivars possess high sensitivity to Zn-deficiency. Thus, to attain the maximum yield potential of wheat and improve grain Zn density, micronutrient management in wheat is an area of research interest, which needs immediate attention. Agronomic biofortification of Zn involves fertilizer application by soil and foliar application (Dhillon and Ram, 2023). Soil application of zinc sulfate before sowing is the most common approach to correct Zn deficiency in crops. Foliar application of Zn seems to be an effective method of ameliorating Zn deficiency and a useful method for enhancing Zn concentration in grain. The timing of the foliar spray of micronutrients is an important factor in determining its effectiveness in increasing grain enrichment of microelements. The highest concentration of Zn in wheat grain occurs at the milking stage (Ozturk *et al.*, 2006). The increase in Zn density in grain is most likely when foliar Zn fertilizers are applied to late growth stages of wheat such as heading initiation, 100% heading, milk stage or dough stage, etc. Zero tillage (ZT) enables timely wheat sowing, saves energy, and enhances soil health and fertility. Additionally, it leads to a

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different Zn distribution in the soil compared to conventional tillage systems, with higher Zn accumulation in the rhizosphere due to residue decay (Naresh *et al.*, 2017). However, there is a lack of information on the effectiveness of various methods of applying Zn fertilizer to enhance the yield, biofortification of grain, and uptake of wheat under zero tillage systems. Therefore, a current study was conducted to determine the impact of Zn fertilization on the yield, concentration, and acquisition of Zn and macronutrients in zero-till wheat.

MATERIALS AND METHODS

Field experiment was conducted during the winter (*rabi*) season of 2018–2019 and 2019–2020 at the Research Farm of Khalsa College, Amritsar, situated at 30°-36' N latitude and 73°-54' E longitude at a mean height of 234 meters above sea level. The study site has a hot moist and semi-arid type of climate with alluvial, medium water holding capacity of soils. The mean minimum and maximum temperature recorded during the growing seasons ranged from 10.2 to 25.2 °C and 10.9 to 24.0 °C, respectively during the year 2018-19 and 2019-20. The average sunshine hours ranged from 5.1 to 6.1 hr/day. The total amount of rainfall in growing seasons was 181 and 253 mm, respectively. The soil of the field was sandy loam, with pH 7.2, EC 0.13 dS/m, organic carbon (0.31%), available nitrogen (248 kg/ha), phosphorus (17.8 kg/ha), and available potassium (275 kg/ha). The available Zn in soil was below the critical level (0.57 mg/kg). The pH was measured using 1:2 soil and water suspension, organic carbon using Walkley and Black's rapid titration method (Walkley, 1934), and available potassium using 1N ammonium acetate extractable K Method (Jackson, 1967), available nitrogen and phosphorus were determined with alkaline potassium permanganate method (Subbiah and Asija, 1956) and 0.5N sodium bicarbonate extractable method (Olsen *et al.*, 1954), respectively. The field experiment consisted of thirteen treatments, *viz.*, T₁ control (no Zn), T₂ 12.5 kg Zn/ha + 0.5% foliar spray at heading initiation, T₃ 12.5 kg Zn/ha + 0.5% foliar spray at 100% heading, T₄ 12.5 kg Zn/ha + 0.5% foliar sprays at heading initiation and 100% heading, T₅ 25 kg Zn/ha + 0.5% foliar spray at heading initiation, T₆ 25 kg Zn/ha + 0.5% foliar spray at 100% heading, T₇ 25 kg Zn/ha + 0.5% foliar sprays at heading initiation and 100% heading, T₈ 37.5 kg Zn/ha + 0.5% foliar spray at heading initiation, T₉ 37.5 kg Zn/ha + 0.5% foliar spray at 100% heading, T₁₀ 37.5 kg Zn/ha + 0.5% foliar sprays at heading initiation and 100% heading, T₁₁ 50 kg Zn/ha + 0.5% foliar spray at heading initiation, T₁₂ 50 kg Zn/ha + 0.5% foliar spray at 100% heading, T₁₃ 50 kg Zn/ha + 0.5% foliar sprays at heading initiation and 100% heading. The treatments were evaluated in random-

ized complete block design with three replications. Zn was applied as per the treatments. The soil application of Zn (ZnSO₄·7H₂O) was applied before sowing of the crop, foliar sprays of 0.5% zinc sulfate heptahydrate (21%) (dissolving in 500 liters of water per hectare during each spray) were applied at heading initiation (5 % ear emergence), 100% heading (complete ear emergence), during evening hours. Wheat variety Unnat (PBW 343) was sown in the first week of November using 100 kg seed/ha under zero-till conditions (collecting loose straw manually and without seedbed preparation) at 22.5 cm row spacing using zero till seed drill in standing rice stubbles. Nitrogen (125 kg/ha), phosphorus (62.5 kg/ha), and potassium (60 kg/ha) were applied at the recommended rates through urea, di-ammonium phosphate, and muriate of potash, respectively. Half a dose of nitrogen and a full dose of phosphorus and potassium were applied at the time of sowing with zero till seed drill. The remaining half dose was applied after the first irrigation. All other recommended packages of practices of Punjab Agricultural University were followed for the successful raising of zero till wheat. Harvested crop produce from the net plot was threshed manually by beating at a hard surface. The grain yield was recorded in kg per plot and expressed in t/ha. Macro and micro-nutrient content at different growth stages and at the time of harvesting in the plant was determined by drying the samples in the hot-air oven at 60°C ± 2° till a constant dry weight was obtained. Nitrogen content in samples was analyzed by using Kjeldahl's apparatus and expressed as a percentage. The P content was determined by using the Vanado-molybdous-phosphoric acid yellow color method (Piper, 1966). The K content was determined by using the flame photometer and was expressed as a percentage. The Zn content in wheat grain and straw was determined using Atomic Absorption Spectrophotometry (AAS). The macro and micro-nutrient uptake was computed by multiplying the nutrient content with respective plant biomass and was expressed as nutrient uptake in kg/ha. Economics was computed based on prevailing market prices of crop produce, inputs, labor, and machinery rent. The data obtained from a two-year study were analyzed statistically as per the procedure given by Gomez and Gomez (1984) using the CPCS1, software. LSD values at P=0.05 were used to determine the significance between the different treatments.

RESULTS AND DISCUSSION

Yield attributes and grain yield

Yield attributes responded significantly to the Zn treatments. Maximum numbers of effective tillers were recorded with the application of 50 kg Zn/ha with two foliar sprays of 0.5 % Zn at heading initiation and 100% heading, which was statistically at par with 37.5 kg Zn/ha, 25 kg Zn/

ha with two foliar sprays of 0.5 % Zn at heading initiation and 100% heading and lowest was recorded in control where no Zn was applied (Table 1). Among the Zn treatments, the application of 50 kg Zn/ha with two foliar sprays of 0.5 % Zn at heading initiation and 100% heading resulted in a maximum number of grains per ear. Zn fertilization has been previously reported to improve yield attributing parameters of wheat like number of tillers and number of grains per ear. All methods of Zn application resulted in significantly higher ear length as compared to the control (no Zn). Among the Zn application methods, 50 kg Zn/ha with two foliar sprays of 0.5 % Zn at heading initiation and 100% heading produced the longest ear length spike which was significantly better than 25 kg Zn/ha with two foliar sprays of 0.5 % Zn at heading initiation and 100% heading. 1000-grain weight represents the boldness of the grain (Table 1). Application of 50 kg Zn/ha with two foliar sprays of 0.5 % Zn at heading initiation and 100% heading was superior in 1000-grain weight (47.5 g) and noticeably higher than the rest of the treatments. The application of Zn might have increased the photosynthetic efficiency due to improved enzymatic activity and thus might have increased thousand-grain weight. These results conform with the findings of Mauriya *et al.* (2015). The grain yield of zero, till responded appreciably to the soil and foliar application of Zn (Table 1.) Significant increase in the grain yield, was observed with the increasing Zn application. Higher grain yield was recorded with 50 kg Zn/ha + 0.5 % foliar spray at heading initiation and 100% heading (5.22 t/ha), which was at par with yield obtained under 37.5 kg Zn/ha + 0.5 % foliar spray at heading initiation and 100% heading, 25 kg Zn/ha + 0.5 % foliar spray at heading initiation and 100% heading and significantly superior to all other treatments. The minimum average grain yield was recorded in control (3.92 t/ha). The increase in yield and yield attributes due to Zn fertilization might be the fact that Zn plays an important role in the biosynthesis of IAA and initiation of primordia for reproductive parts. Zn is an important component and co-factor of several enzymes, cell division, and elongation, which helps plants maintain different biochemical activities for better crop growth, better physiology, more biofortified grains, and greater yield. These results conform with those of Faizal *et al.* (2021) and Dewal *et al.* (2004).

Nutrient concentration

The effect of zinc application on N, P, and K contents was found statistically identical; although a

Table 1. Effect of various zinc treatments on yield attributes, yield and economics of zero tilled wheat (pooled data of 2 years)

| Treatment | Effective tillers/m ² | Ear length (cm) | Grains/ear (Nos.) | 1000-grain weight (g) | Grain yield (t/ha) | Gross return (₹ x 10 ³ /ha) | Net return (₹ x 10 ³ /ha) | Additional income over control (₹/ha) |
|--|----------------------------------|-----------------|-------------------|-----------------------|--------------------|--|--------------------------------------|---------------------------------------|
| Control (no zinc) + NPK (Recommended) | 284 | 9.2 | 37.9 | 38.2 | 3.93 | 71.13 | 42.44 | - |
| 12.5 kg Zn/ha + foliar spray of 0.5% Zn at heading initiation | 318 | 9.6 | 39.7 | 39.6 | 4.06 | 76.74 | 47.80 | 5355 |
| 12.5 kg Zn/ha + foliar spray of 0.5% Zn at 100% heading | 323 | 10.1 | 40.0 | 41.6 | 4.21 | 78.85 | 49.91 | 7467 |
| 12.5 kg Zn/ha + foliar spray of 0.5% Zn at heading initiation and 100% heading | 331 | 9.4 | 41.4 | 43.6 | 4.36 | 81.23 | 52.29 | 9848 |
| 25 kg Zn/ha + foliar spray of 0.5% Zn at heading initiation | 339 | 9.6 | 40.2 | 41.8 | 4.54 | 84.99 | 55.80 | 13351 |
| 25 kg Zn/ha + foliar spray of 0.5% Zn at 100% heading | 351 | 10.2 | 42.4 | 47.0 | 4.69 | 87.89 | 58.70 | 16252 |
| 25 kg Zn/ha + foliar spray of 0.5% Zn at heading initiation and 100% heading | 373 | 11.2 | 44.1 | 47.3 | 4.82 | 92.75 | 63.56 | 21116 |
| 37.5 kg Zn/ha + foliar spray of 0.5% Zn at heading initiation | 344 | 9.8 | 41.1 | 43.1 | 4.67 | 91.89 | 62.45 | 20005 |
| 37.5 kg Zn/ha + foliar spray of 0.5% Zn at 100% heading | 353 | 10.4 | 42.2 | 44.8 | 4.75 | 92.84 | 63.40 | 20953 |
| 37.5 kg Zn/ha + foliar spray of 0.5% Zn at heading initiation and 100% heading | 372 | 10.7 | 44.4 | 46.9 | 5.11 | 96.81 | 67.36 | 24921 |
| 50 kg Zn/ha + foliar spray of 0.5% Zn at heading initiation | 346 | 11.1 | 41.5 | 43.8 | 4.75 | 92.82 | 63.13 | 20684 |
| 50 kg Zn/ha + foliar spray of 0.5% Zn at 100% heading | 365 | 11.3 | 42.4 | 45.8 | 4.85 | 94.15 | 64.46 | 22018 |
| 50 kg Zn/ha + foliar spray of 0.5% Zn at heading initiation and 100% heading | 374 | 11.5 | 44.8 | 47.5 | 5.25 | 98.43 | 68.74 | 26295 |
| SEM± | 2.6 | 0.1 | 0.4 | 0.3 | 0.88 | - | - | - |
| CD (P=0.05) | 8.42 | 0.78 | 1.51 | 1.36 | 0.32 | - | - | - |

numerically higher value was observed with the application of 50 kg Zn/ha + 0.5 % foliar sprays at heading initiation and 100 % heading. Non-significant effects of Zn fertilizations on N,P, and K contents might be due to the application of recommended doses of N,P, and K fertilizers in all the treatments. The significant increase in N,P, and K contents with application of Zn was also reported by Singh *et al.* (2024). Zn concentration in grains and straw of zero till wheat increased significantly with different rates of Zn treatment (Table 2). The highest concentrations of Zn were recorded in grain (41.77ppm) with the application of 50 kg Zn/ha + 0.5 % foliar sprays at heading initiation and 100 % heading, which was 33.92% higher over the control (31.19 ppm). A similar trend in Zn content in straw was recorded as Zn content in grains. It was affected statistically with the various Zn treatments but it increased with all treatments over the control. The range of Zn varied from 24.52 to 18.15 mg/kg in the straw of zero till wheat. This might be attributed to the genetic potential of nutrient content and acquisition. The acquisition of nutrients by the crop depends upon the dry matter production and nutrient content in plant parts (Yadav *et al.*, 2016).

Nutrient acquisition

Total nutrient uptake (acquisition) by wheat (grain and straw) was influenced by various Zn treatments. Total N, P, K, and Zn uptake by wheat was the highest with the application of 50 kg Zn/ha + 0.5 % foliar sprays at heading initiation and 100 % heading, (163.17kg/ha, 23.47kg/ha, 15.21 kg/ha and 408.31 kg/ha) which was remarkably better than other treatments (Fig. 1). The lowest total N, P, K and Zn uptake was recorded in control, where no Zn was applied. The magnitude of increase in N, P, K, and Zn uptake with 50 kg Zn/ha + 0.5 % foliar sprays at heading initiation and 100 % heading was 49.7, 64.0 45.2, and 80.1% in wheat (grain and straw), respectively, over the control. Zn influenced the growth and grain yields of crops possibly through accelerated uptake and transport of beneficial nutrients like N, P, K, and Zn in plants. These results are following the findings of Chaudhary *et al.* (2014). Zn interacts positively with nitrogen and potassium and negatively with phosphorus in plants. The improvement in dry matter accumulation and nutrient contents ultimately led to higher uptake of nitrogen, phosphorus, potassium, and Zn (Parshad *et al.*, 2016).

Table 2. Effect of various zinc treatments on, N, P, K and Zn content of zero tilled wheat (pooled data of 2 years)

| Treatments | N (%) | | P (%) | | P (%) | | Zn (ppm) | |
|--|-------|-------|--------|--------|-------|-------|----------|-------|
| | Grain | Straw | Grain | Straw | Grain | Straw | Grain | Straw |
| Control (no zinc) + NPK (Recommended) | 1.83 | 0.64 | 0.30 | 0.044 | 0.39 | 1.60 | 31.20 | 18.15 |
| 12.5 kg Zn/ha + foliar spray of 0.5% Zn at heading initiation | 1.85 | 0.65 | 0.31 | 0.045 | 0.40 | 1.62 | 32.67 | 20.00 |
| 12.5 kg Zn/ha + foliar spray of 0.5% Zn at 100% heading | 1.86 | 0.65 | 0.32 | 0.045 | 0.41 | 1.62 | 33.01 | 20.21 |
| 12.5 kg Zn/ha + foliar spray of 0.5% Zn at heading initiation and 100% heading | 1.87 | 0.66 | 0.33 | 0.047 | 0.42 | 1.64 | 33.32 | 20.41 |
| 25 kg Zn/ha + foliar spray of 0.5% Zn at heading initiation | 1.89 | 0.67 | 0.34 | 0.048 | 0.42 | 1.65 | 35.12 | 21.16 |
| 25 kg Zn/ha + foliar spray of 0.5% Zn at 100% heading | 1.91 | 0.68 | 0.33 | 0.048 | 0.43 | 1.66 | 35.81 | 22.20 |
| 25 kg Zn/ha + foliar spray of 0.5% Zn at heading initiation and 100% heading | 1.98 | 0.70 | 0.34 | 0.053 | 0.43 | 1.67 | 40.80 | 24.31 |
| 37.5 kg Zn/ha + foliar spray of 0.5% Zn at heading initiation | 1.93 | 0.70 | 0.35 | 0.050 | 0.44 | 1.67 | 38.75 | 23.06 |
| 37.5 kg Zn/ha + foliar spray of 0.5% Zn at 100% heading | 1.94 | 0.71 | 0.35 | 0.051 | 0.44 | 1.66 | 39.17 | 23.31 |
| 37.5 kg Zn/ha + foliar spray of 0.5% Zn at heading initiation and 100% heading | 1.97 | 0.72 | 0.36 | 0.053 | 0.45 | 1.67 | 41.29 | 24.29 |
| 50 kg Zn/ha + foliar spray of 0.5% Zn at heading initiation | 1.95 | 0.73 | 0.35 | 0.053 | 0.45 | 1.68 | 39.81 | 23.74 |
| 50 kg Zn/ha + foliar spray of 0.5% Zn at 100% heading | 1.95 | 0.75 | 0.37 | 0.055 | 0.46 | 1.69 | 40.04 | 23.99 |
| 50 kg Zn/ha + foliar spray of 0.5% Zn at heading initiation and 100% heading | 2.00 | 0.75 | 0.37 | 0.056 | 0.47 | 1.69 | 41.77 | 24.52 |
| SEM± | 0.03 | 0.05 | 0.0045 | 0.0006 | 0.016 | 0.04 | 0.29 | 0.05 |
| CD (P=0.05) | NS* | NS | NS | NS | NS | NS | 1.14 | 0.24 |

NS, non-significant

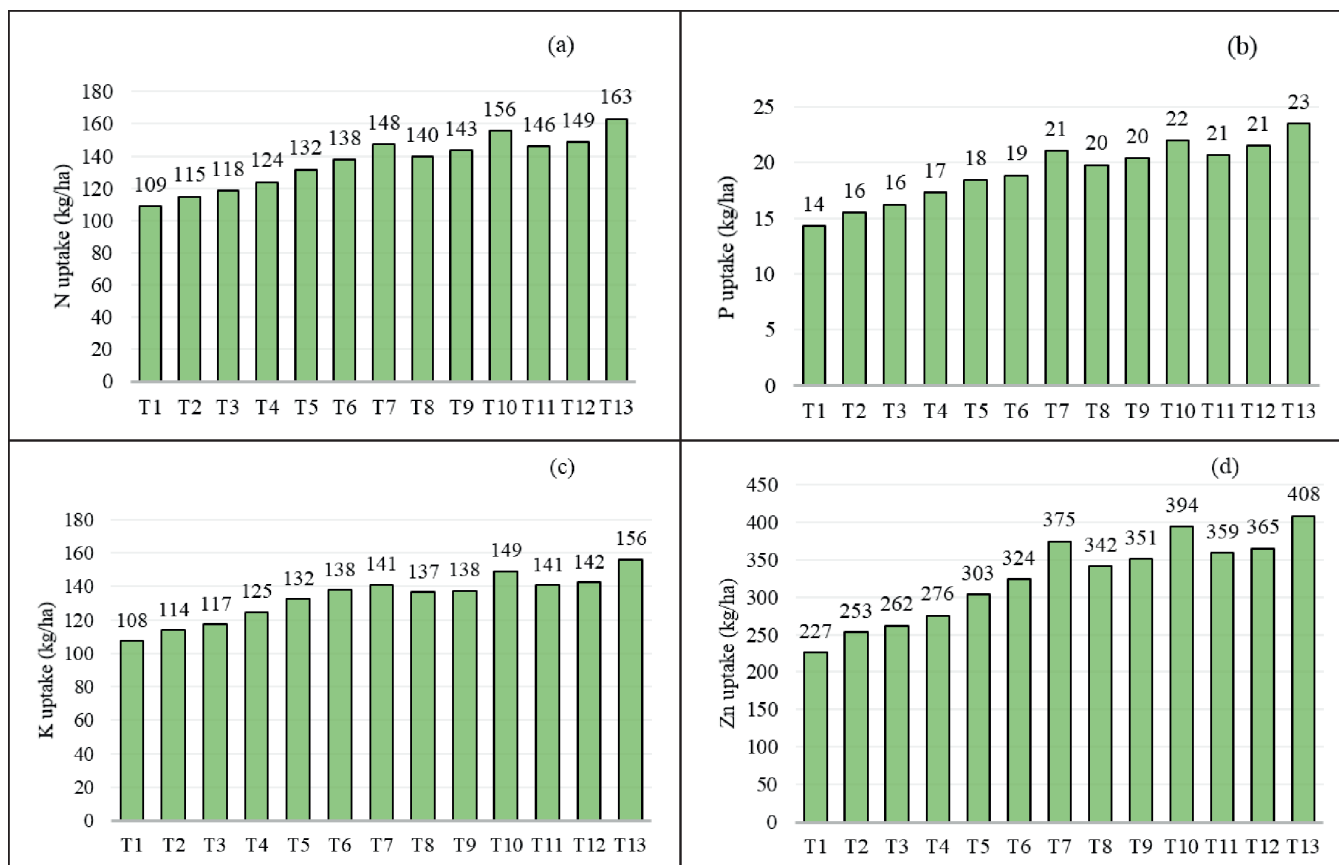


Fig. 1. Effect of various zinc treatments on N, P, K and Zn uptake of zero tilled wheat

Economics

In the current study, the net returns increased with the increase in Zn treatments over the control. Net returns among the Zn treatments varied from ₹42.44 to 68.74 $\times 10^3$ /ha. The application of 50 kg Zn/ha + foliar spray of 0.5% Zn at heading initiation and 100% heading resulted in 26.29 ₹ $\times 10^3$ /ha additional net returns over control. The increase in the grain yield leading to the higher economic return is attributable to the improved physiology of plants with the added Zn consequently enhancing the efficiency of different enzymes leading to higher yield.

Thus, it may be concluded that soil application of 50 kg Zn/ha along with two foliar sprays of Zn @ 0.5% at heading initiation and 100% heading produced ~25% higher grain yield, besides higher Zn concentration and acquisition by zero till wheat over control (no Zn). Hence, it can be recommended for quality wheat production in Punjab under zero-till conditions.

REFERENCES

- Cakmak, I. 2008. Enrichment of cereal grain with zinc: Agronomic or genetic biofortification. *Journal of Plant and Soil Science* **302**: 1–17.
- Chattha, M.U., Hassan, M.U., Khan, I., Chattha, M. B., Mahmood, A. and Nawaz, M. 2017. Biofortification of wheat cultivars to combat zinc deficiency. *Frontier in Plant Science* **8**: 1–8.
- Chaudhary, S., Singh, H., Singh, S. and Singh, V. 2014. Zinc requirement of green gram (*Vigna radiata*)–wheat (*Triticum aestivum*) crop sequence in alluvial soil. *Indian Journal of Agronomy* **59**(1): 48–52.
- Dewal, G.S. and Pareek, R.G. 2004. Effect of phosphorus, sulphur and zinc on growth, yield and nutrient uptake of wheat (*Triticum aestivum*). *Indian Journal of Agronomy* **49**(3): 160–162.
- Dhillon, B.S. and Ram H. 2023. Micro-meteorological parameters, growth indices and productivity of barley (*Hordeum vulgare*) cultivars as influenced by clipping and zinc biofortification. *Indian Journal of Agronomy* **68**(3): 279–286 <https://doi.org/10.59797/ija.v68i3.2807>
- Faizan M., Bhat J.A., Chen C., Alyemini M.N., Wijaya L. and Ahmad P. 2021. Zinc oxide nano particles induce salt tolerance by improving the antioxidant system and photosynthetic machinery in tomato. *Plant Physiology and Biochemistry* **161**: 122–130.
- Gomez, K. A. and Gomez, A.A. 1976. *Statistical Procedures for Agri Research*. 367–72.
- Groote, H., Tessema, H., Gameda, S. and Gunarantna, N.S. 2021. Soil zinc, serum zinc and the potential for agronomic biofortification to reduce human zinc deficiency in Ethiopia. *Science Report* **11**(1): 8,770–8,774.
- Jackson, M.L. 1967. Soil chemical analysis. *New Delhi: Prentice hall of India, Private Limited*.
- Kumssa, D.B., Joy, E.J.M., Ander, E.L., Watts, M.J.L., Young, S.D., Rosano, A., White, P.J., Walker, S. and Broadley, M. R.

2015. Global magnesium supply in the food chain. *Crop Pasture Science* **66**: 1,278–1,289.
- Mauriya, A.K., Maurya, D.C., Maurya, V.K. and Verma, R.K. 2015. Effect of zinc application methods on yield attributes, yield and nutrient uptake in wheat (*Triticum aestivum*) varieties under sodic soil. *Indian Journal of Agronomy* **60**(1): 82–86.
- Nadeem, F. and Farooq, M. 2019. Application of micronutrients in rice-wheat cropping systems of South Asia: A review. *Rice Science* **26**: 356–371.
- Naresh, R.K., Timsina., Bhaskar, S., Gupta, R.K., Singh, A.K., Dhaliwal, S.S., Rathore, R.S., Kumar, V. and Singh, P. 2017. Effects of tillage, residue and nutrient management on soil organic carbon dynamics and its fractions, soil aggregate stability and soil carbon sequestration: A review. *EC- Nutritions* **12**: 53–80.
- Olsen, S.R., Cole, C.V., Waternade, F.S. and Dean, L.A., 1954. Estimation of available phosphorous in soil by extraction with sodium bicarbonate. *USDA Circular* 939.
- Ozturk, L., Yazici, M.A., Yucel, C., Torun, A., Cekic, C., Bagci, A., Ozkan, H. and Cakmak, I. 2006. Concentration and localization of zinc during seed development and germination in wheat. *Journal of Plant Physiology* **128**: 144–152.
- Piper, C.S. 1966 *Soil and Plant Analysis*. Pp. 368. Hans publisher, Bombay.
- Prasad, R., Shivay, Y.S. and Kumar, D. 2016. Interactions of zinc with other nutrients in soils and plants. *Indian Journal of Fertilizers* **12**: 16–26.
- Singh, S., Singh, V. and Kumar, M. 2024. Effect of zinc and boron on grain quality of wheat (*Triticum aestivum*) in north-western plain zone of India. *Indian Journal of Agronomy* **69**(1): 44–47. DOI: 10.59797/ija.v69i1.5480
- Subbiah, B.V. and Asija, G.L. 1956. A rapid procedure for the estimation of available nitrogen in soils. *Current Science* **25**: 259–260.
- Walkley, A.J. and Black, I.A. 1934. Estimation of soil organic carbon by the chromic acid titration method. *Soil Science* **37**: 29–38.
- Yadav, A., Babu, S., Krishnan, P., Kaur, B., Bana, R.S., Chakraborty, D., Kumar, V., Joshi, B. and Lal, S.K. 2024. Zinc oxide and ferric oxide nanoparticles combination increase plant growth, yield, and quality of soybean under semiarid region. *Chemosphere*. doi: 10.1016/j.chemosphere.2024.141432.
- Yadav, G.S., Shivay, Y.S., Kumar, D. and Babu S. 2016. Agronomic evaluation of mulching and iron nutrition on productivity, nutrient uptake, iron use efficiency and economics of aerobic rice-wheat cropping system. *Journal of Plant Nutrition* **39**(1): 116–35. <https://doi.org/10.1080/01904167.2015.1084323>
- Zulfiqar, U., Maqsood, M., Hussain, S. and Anwar-ul-Haq, M. 2020. Iron nutrition improves productivity, profitability and biofortification of bread wheat under conventional and conservation tillage systems. *Journal of Soil Science and Plant Nutrition* **4**: 1–18.

Yields, nutrient-use efficiencies and production economics of wheat (*Triticum aestivum*) as influenced by foliar nano urea

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ABSTRACT

The nano fertilizers are becoming popular in crop production sector due to their higher nutrient use efficiency and also enhance the productivity and quality while requiring less input and being environmentally safe. In order to assess the effect of foliar application of nano urea on growth and yield performances of wheat (*Triticum aestivum* L.) and to evaluate nitrogen-use efficiency under integrated use of nano urea, this study was undertaken during the *rabi* seasons of 2021–22 and 2022–23 at the Uttar Banga Krishi Viswavidyalaya, Pundibari, West Bengal. The experiment was laid-out in a randomized block design (RBD) having 13 treatments consisting of foliar application of water, nano urea (once at tillering and twice at tillering and jointing) and 5% urea in combination with each of 50, 75 and 100% of recommended nitrogen doses (RDN) along with a control (without N), and each treatment was replicated thrice. It was observed that foliar application of nano urea (0.4%) twice at tillering and jointing stages with 100% (RDN 5,759 kg/ha) was statistically at par with 100% RDN + 5% foliar spray of urea twice at tillering and jointing stage (5,985 kg/ha) in terms of grain yield, the latter being the highest yielder. Foliar application of either urea or nano urea by curtailing 25-50% RDN did not brought about superior growth and yield performances. Under each level of RDN (100%, 75% and 50%), foliar application of 5% urea was a bit superior to nano urea, though the difference was not statistically significant. However, nano urea reflected higher nitrogen-use efficiency under all levels RDN; partial factor productivity of nitrogen (PFP_N) and agronomic nitrogen-use efficiency (ANUE) values being the highest under 50% RDN along with two spraying of nano urea (56.76 and 24.50 kg grain/kg N). The treatment comprising 100% RDN+ 5% spray of urea at tillering and jointing stages resulted in the highest net return (69608 ₹/ha) and B: C ratio (2.58), closely followed by the treatment comprising nano urea application twice (gross return, net return and B: C ratio of 109,426 ₹/ha, 63,748 ₹/ha and 2.40, respectively) with 100% RDN, being statistically *at par* with each other. It can be concluded from this two-year trial that only foliar application of nano urea by curtailing soil nitrogen application to 25-50% resulted in reduced yield performances of wheat; nano urea had promote effects on yields when it was applied along with 100% RDN.

Key words: Nano urea, Nitrogen-use efficiencies, Profitability, Wheat

Conventional chemical fertilizers are extensively used throughout the globe for achieving higher yields in agricultural production system. Considering the increasing population and diminishing agricultural land, it is becoming necessary to use chemical fertilizers, especially nitrogen to meet the growing food demands (Abebe *et al.*, 2022). Only urea, the chief nitrogenous fertilizer, accounts for more than 82% of the nitrogenous fertilizers applied to

crop and globally, 188 million metric tonnes of urea is applied to crops every year. Though nitrogen fertilization is a crucial agronomic management technique for improving the vegetative growth of crops targeting increased crop productivity, but indiscriminate use has environmental and ecological consequences (Pachauri and Meyer, 2014; Mahmud *et al.*, 2021). Again, the nitrogen-use efficiency (NUE) in agricultural systems has remained low (rarely exceeds 30-35%) despite prior efforts, revealing that over half of the N added to agricultural soils may be lost to the environment globally (Al-Juthery *et al.*, 2021). The scientists, policy makers, industrialists as well as farmers are concerned about the ill effects and are looking for some alternate sources. The nano fertilizers are believed to have the potential for a paradigm shift in agriculture (Bartolucci

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et al., 2022). The nano fertilizers possess more surface area along with slow and plant response-based release (Raliya *et al.*, 2018). It can reduce nutrient losses through leaching and gaseous emissions and thus ensures a sustainable production system (Iqbal 2020).

IFFCO has developed a new nano fertiliser called 'nano urea' on 5th June 2021 with an objective to replace or reduce the ill effects of urea. The nano fertilizers are any products that are made up of nanoparticles or that uses nanotechnology to improve nutrient efficiency in the form of fertilizers and in crop production sector, it enhances the productivity and quality while requiring less input, reducing input costs and environmentally safe (Kiran and Samal, 2021; Kumar *et al.*, 2021b). The efficacy of IFFCO nano urea has been tested in various crops in various locations and the initial studies indicated a possibility of curtailing fertilizer doses through use of nano urea but the response varied from crop to crop. In recent times, the use of nano urea is becoming popular among the farming community, but its effectiveness in high nitrogen requiring crops are under question mark.

In eastern plains, wheat (*Triticum aestivum* L.) is one of the most significant and primary food crops and has huge importance in maintaining food security of the country. Balanced nutrition is the key through which we can improve the production scenario of wheat cultivation. Again, precision nitrogen management for wheat depends on use of NDVI sensor, leaf colour charts, decision support tools like Nutrient Expert which are gaining popularity in scheduling nitrogen to wheat crop (Mitra *et al.*, 2019, Singha and Mitra, 2020; Mitra *et al.*, 2023a). Various field-based studies (Mondal *et al.*, 2018; Mitra *et al.*, 2023b) indicated higher nitrogen demand for wheat genotypes (150 kg/ha or even more) in eastern plains. Nano urea may be a potential alternative for wheat through which the soil chemical load can be curtailed. Keeping this in backdrop, this study was undertaken to assess the effect of nano urea on growth and yield performances of wheat *vis-à-vis* nitrogen-use efficiency under integrated use of nano urea.

MATERIALS AND METHODS

The field trial was conducted at All India Coordinated Wheat and Barley Improvement Project (AICW & BIP) Block of Uttar Banga Krishi Viswavidyalaya, Pundibari, West Bengal (26° 19'86" N latitude, 89° 23' 53" E longitude and at an elevation of 43 meters above mean sea level) during the *rabi* seasons of 2021–2022 and 2022–2023. The soil was sandy loam in texture, slightly acidic (pH 5.94) in reaction, medium in organic carbon (0.67%), low in mineralizable nitrogen (171.3 kg/ha) and available potassium (130.6 kg/ha) and high in available phosphorus (36.7 kg/ha).

The experiment was laid-out in a randomized block de-

sign (RBD) having 13 treatments, *viz.* T₁, 100% Recommended nitrogen doses (RDN) + water spray at tillering and jointing; T₂, 100% RDN + single spray of nano urea at tillering; T₃, 100% RDN + two sprays of nano urea at tillering and jointing; T₄, 100% RDN + two sprays of 5% urea at tillering and jointing; T₅, 75% RDN + water spray at tillering and jointing; T₆, 75% RDN + single spray of nano urea at tillering; T₇, 75% RDN + two sprays of nano urea at tillering and jointing; T₈, 75% RDN + two sprays of 5% urea at tillering and jointing; T₉, 50% RDN + water spray at tillering and jointing; T₁₀, 50% RDN + single spray of nano urea at tillering; T₁₁, 50% RDN + two sprays of nano urea at tillering and jointing; T₁₂, 50% RDN + two sprays of 5% urea at tillering and jointing and T₁₃, control (without N only), each treatment was replicated thrice. As the effects of one or two applications of nano urea was tested against 5% urea spraying under each of 50,75 and 100% RDN, the number of treatments was higher. The recommended N dose was kept at 150 kg/ha following all India recommendations; while P₂O₅ and K₂O were applied @ 60 and 40 kg/ha, respectively in all the treatments. One-third of nitrogen in the form of urea was applied as basal during final land preparations while rest two-third was applied in two equal splits at crown root initiation and active tillering stage. Urea topdressing was followed by irrigation for assured moisture. The full doses of phosphorus and potassium were applied during final land preparation in the form of single super phosphate and muriate of potash, respectively. The IFFCO nano urea (liquid) containing 4% N (500 ml commercial pack @ 240.00) as encapsulated nitrogen analogues was used as a source of nano urea. In this product the particle size is 20-50 nm as per scanning electron micrography as claimed by IFFCO. The foliar application of nano urea was done using 0.4% concentration (standardised dose for wheat) with a spray volume of 450 L/ha. Foliar spray of urea at 5% concentration was prepared by the addition of urea fertilizer in water (w/v) (50 g/ 1 litre). The wheat variety used in the experiment was DBW 187 (Karan Vandana), a blast resistant high yielding variety rich in Fe and Zn, recommended for north eastern plain zone (NEPZ) matures in 115-120 days. The crop was sown in lines 20 cm rows apart with a continuous seeding in lines on November 21 during both the years with a seed rate 100kg/ha. The tiller number and dry matter accumulation was estimated at periodical intervals whereas the yield attributes were taken at harvest. The entire produce from the net plot area of 12.8 m² (8 rows of 1 m length with 20 cm spacing) was harvested and weighed after thorough drying under the sun. Grain and straw yield from that area was converted into per unit area basis (kg/ha). The estimated values of partial factor productivity of N (PFP_N) and agronomic nitrogen-use efficiency (ANUE) were

calculated as per formula given by Dobermann (2007):

$$\text{Partial factor productivity (kg grain / kg of N)} = \frac{Y_t}{N_a}$$

Where, Y_t = Yield under treatment (kg/ha)

N_a = Amount of nutrient added (kg/ha)

$$\text{Agronomic N-use efficiency (kg grain/kg N)} = \frac{Y_t - Y_o}{A_t}$$

Where, Y_t = Yield under test treatment (kg/ha)

Y_o = Yield under control (kg/ha)

A_t = Unit nutrient applied in the treatment (kg/ha)

Total cost of production/ha for each treatment was calculated on the basis of existing market rate of inputs (seeds, fertilizers, micronutrients, herbicides, etc including nano urea) and wage-rate of the labourers. The gross return was calculated by considering the output prices of wheat grains prevailing in the local market. The net return was calculated by deducting the cost of cultivation from the gross return/ha. The benefit-cost ratio was calculated as a proportion of gross returns and the total cost of cultivation and on the basis of benefit: cost ratio, the most beneficial treatment for the crop sequence was determined.

Analysis of variance (ANOVA) for randomised block design was done as per the procedure given by Gomez and Gomez (1984) using SPSS window version 17.0 (SPSS Inc., Chicago, USA). For pooled analysis, year was taken as a main factor and the significant differences between treatments were compared with the critical difference (CD) at 5% level of probability.

RESULTS AND DISCUSSION

Growth attributes

The maximum plant height (96.8 cm) was achieved with 100% RDN + 2 sprays of nano urea at tillering and jointing (T_3), being statistically *at par* with 100% RDN + 2 sprays of 5% urea at tillering and jointing (T_4) and 100% RDN + single spray of nano urea at tillering (T_2) treatments. Spraying of nano urea twice at tillering and jointing stages along with 100% RDN might be effective in better release of nutrients which favours the crop growth by increasing the cell elongation. It was noted that the plant height didn't reduce to that extent even after curtailing 25 - 50 % of the RDN. However, the lowest plant height (74.8 cm) was noted in the control treatment where N application was skipped. The results obtained are in conformity with the findings of Jyothi and Hebsur (2017) and Ehsan *et al.* (2021) who found the highest plant height with nano fertilizer application in combination with 100% recommended dose of nitrogen. At 60 days after sowing (DAS), the maximum tiller number (338/m²) was observed in the treatment in which 100% RDN was given along with 2 foliar sprays of urea 5% at tillering and jointing stages (T_4) and it was statistically at par with 100% RDN + 2 sprays of nano urea at tillering and jointing (T_3) (328/m²), 100 % recommended

dose of nitrogen + 1 spray of nano urea (319/m²) (T_2). It was also observed that 75% RDN along with one or two sprays of nano urea or even 5% urea also produced similar tiller number (Table 1). Due to tiller mortality, the total tiller number reduced a bit in the later part irrespective of the treatments but the overall trend was similar. It was evident that reducing the nitrogen rates by 25%, there was 8-10% reduction in total tiller number but 50% curtailment in RDN resulted in 15-20% reduction. Nitrogen is essential for promoting plant's vegetative growth. Therefore, any reduction in nitrogen doses revealed some kind of retardation in growth parameters. However, spraying of nano urea once or twice was quite effective and similar to that of 5 % urea spraying which increased nitrogen availability for crop plants to explore, so there was improved nutrient uptake by plant cells leading to optimum growth which was reflected in terms of tiller number. These results corroborated with the findings of Ahmed and Fahmy (2017) who found that application of nano fertilizers increased the tiller number. The treatment consisting of 100% RDN with 2 sprays of 5% urea at tillering and jointing stages also recorded the highest aerial biomass i.e., 169.8 g/m² at 30 DAS, 635.5 g/m² at 60 DAS and 1250.1 g/m² at 90 DAS. The results also showed that the dry matter accumulation in treatments with 100% RDN combined with 2 sprays (T_3) or single spray (T_2) of nano urea was statistically at par with the highest values obtained with recommended nitrogen plus two sprays of 5% urea. Increased dry matter accumulation at 100% N application might be due to adequate nutrition obtained from higher nitrogen application levels. The plant's vegetative growth was further accelerated by the use of nano urea or foliar application of 5% urea, as evidenced by a higher number of tillers. The results are in conformity with the results of Martinez *et al.* (2020). Increase in tiller number and leaf area attributed to higher accumulation of aerial biomass. Spraying of nano urea triggers positive crop response as it improves nutrient availability in the rhizosphere (Kumar *et al.*, 2021a). Its application enhances plant metabolic processes, promotes meristematic activities, ensures higher leaf photosynthetic area and triggers enzyme for improving growth and yields of the plant (Preetha and Balakrishnan, 2017). When sprayed on leaves, it easily gets absorbed and enters through stomata due to its nano size. Thus, it utilises the dynamics of shape, size, surface area for better assimilation (Kumar *et al.*, 2021a) which, in turn, leads to higher growth and yields of crop plants.

Yield attributes and yield

The number of spikes/m² varied significantly with nano urea application. The treatment T_4 (100% recommended dose of nitrogen with 2 sprays of 5% urea at tillering and

Table 1. Growth parameters of wheat as influenced by nano urea (pooled data of 2 years)

| Treatments | Plant height (cm) | Tiller number/ m ² | | | Dry matter accumulation (g/m ²) | | |
|--|----------------------|----------------------------------|--------|--------|--|--------|--------|
| | | 60 DAS | 75 DAS | 90 DAS | 30 DAS | 60 DAS | 90 DAS |
| T ₁ , 100 % RDN + 2 water sprays at tillering and jointing | 90.51 | 310 | 300 | 295 | 174.3 | 532.3 | 1089.4 |
| T ₂ , 100 % RDN + single spray of nano urea at tillering | 92.00 | 319 | 312 | 306 | 185.2 | 556.2 | 1158.1 |
| T ₃ , 100 % RDN + 2 sprays of nano urea at tillering and jointing | 96.80 | 328 | 319 | 314 | 179.4 | 607.8 | 1214.2 |
| T ₄ , 100 % RDN + 2 sprays of urea (5%) at tillering and jointing | 94.80 | 338 | 330 | 324 | 169.8 | 635.5 | 1250.1 |
| T ₅ , 75 % RDN + 2 water sprays at tillering and jointing | 92.00 | 295 | 290 | 282 | 168.5 | 490.8 | 989.4 |
| T ₆ , 75 % RDN + single spray of nano urea at tillering | 93.80 | 310 | 297 | 290 | 165.2 | 513.9 | 1054.3 |
| T ₇ , 75 % RDN + 2 sprays of nano urea at tillering and jointing | 95.30 | 315 | 307 | 300 | 170.6 | 540.1 | 1102.8 |
| T ₈ , 75 % RDN + 2 sprays of urea (5%) at tillering and jointing | 94.40 | 323 | 314 | 310 | 159.9 | 589.0 | 1159.8 |
| T ₉ , 50 % RDN + 2 water sprays at tillering and jointing | 86.30 | 284 | 275 | 267 | 130.8 | 431.5 | 868.3 |
| T ₁₀ , 50 % RDN + single spray of nano urea at tillering | 89.50 | 284 | 277 | 272 | 134.8 | 466.8 | 925.8 |
| T ₁₁ , 50 % RDN + 2 sprays of nano urea at tillering and jointing | 89.70 | 295 | 290 | 283 | 133.0 | 501.4 | 943.0 |
| T ₁₂ , 50 % RDN + 2 sprays of urea (5%) at tillering and jointing | 90.80 | 302 | 298 | 293 | 134.2 | 520.8 | 969.9 |
| T ₁₃ , Control (No N application) | 74.80 | 228 | 224 | 215 | 108.7 | 271.9 | 620.4 |
| SEm± | 2.01 | 10.3 | 9.9 | 10.5 | 3.9 | 11.8 | 23.1 |
| CD (P=0.05) | 5.90 | 30.3 | 28.9 | 30.9 | 11.3 | 34.5 | 67.8 |

RDN, Recommended dose of nitrogen; DAS, days after sowing

jointing) recorded the highest number of spikes/m² (320); being statistically at par with nano urea application twice (310) or once (304) with 100% RDN. Foliar spray of 5% urea at tillering and jointing stage along with 100 % RDN also recorded the highest number of filled grains/spike (46.3) though the number of filled grains/spike attained under the different N scheduling treatments did not differ significantly except control which recorded the lowest filled grains/spike (32.7). The results showed that the test-weight of wheat, being a genetic character, did not differ significantly by the different nitrogen treatments except control. The results are in conformity with the findings of Dapekar *et al.* (2018). In addition to timely nitrogen supply, foliar spray of urea might be leading to increased photosynthetic absorption and translocation of photosynthates from the source to the sink, which, in turn, might have contributed to an increased number of spikes and grains within a spike (Kumar *et al.*, 2021a). Nano urea releases nitrogen twelve times slower than the urea and thus is available for functional metabolic interaction over a longer period (Saurabh *et al.*, 2019). Even nano urea spraying before flowering (as sprayed in jointing in this trial) improves

source-sink relationship and helps in translocation of photosynthates towards grain (Upadhyay *et al.*, 2023). The results corroborated with the findings of Bakhtiari *et al.* (2015) and Al-Juthery *et al.* (2018) who found increased spike number using nano fertilizers. A small reduction in spike length was observed with the treatments in which RDN was curtailed by 25–50%. There was increase in spike length under 100% RDN due to increased apical growth and meristematic activity.

The treatment T₄ (100% RDN + 2 foliar sprays of urea at tillering and jointing) resulted in the highest grain yield (5985 kg/ha), followed by the treatment T₃ (100% RDN + 2 sprays of nano urea at tillering and jointing) (5759 kg/ha), being statistically *at par* with each other. Following the similar trend of grain yield, the highest straw yield (8798 kg/ha) was also recorded with T₄ treatment, closely followed by T₃ treatments, being statistically *at par* with each other. Under 100% RDN, one and two sprays of nano urea brought 4.1 and 14.1% yield enhancement while under 75% RDN, the increase in grain yields was 2.5 and 6.1% over no foliar application treatment; while 5% urea foliar application twice resulted in 18.5 and 17.2% yield en-

hancement over no foliar application. It reflected that for enhanced growth and yield of crop, foliar spraying of urea was more efficient than nano urea when soil was supplied with sufficient nutrient elements as under 100% and 75% RDN. It was also noted that the yields were almost equivalent when two sprays of nano urea were applied along with 75% RDN, thus saving 25% of soil applied nitrogen. Again, 5% urea foliar application with 75% RDN brought about 8.7% yield enhancement over 100% RDN. Foliar application of urea and nano urea also resulted in yield enhancement even under 50% RDN, but the magnitude of enhancement in yields was lesser. With 50% curtailment in RDN, grain yield reduced by 21% and the reduction was steeper (26%) under 50% RDN plus 5% urea over 100% RDN plus 5% urea. The active ingredients in nano fertilizers are specifically designed to release nutrients in response to biological demands and environmental stress, thereby increasing agricultural productivity through improved photosynthetic activity, growth of seedlings, rate of seed germination, nitrogen metabolism, and synthesis of carbohydrates and proteins (Al-Juthery *et al.*, 2019). The results showed that foliar application of nano urea twice during the active tillering and jointing stages, would be highly beneficial for increasing the grain and straw yields when soil N levels are adequate. Under sufficient level of soil nitrogen, both urea and nano urea foliar application was highly beneficial and impactful for the crop. These results

are in conformity with the findings of Mehta and Bharat (2019). The straw yield decreased correspondingly in cases when the grain yield reduced as a result of inadequate nutrition, indicating no obvious impact on the harvest index. Mehta and Bharat (2019) also found that there was no significant difference in the harvest index values among different nitrogen treatments. The grain and straw yields were largely dependent on soil nitrogen application. Foliar application of urea or nano urea could substantiate a portion of it. That's why in our trial, both grain and straw yields decreased with curtailment of soil applied N. But it was noted that nano urea or urea foliar application could substantiate 25% curtailment as the yields with 75% RDN plus twice spraying of urea 5% or nano urea 0.4% were similar or higher. In all the cases, 5% urea foliar application superseded 0.4% nano urea in terms of yields. However, further curtailment resulted in a considerable yield drop (11-20%) even with spraying of urea or nano urea. It was quite indicative that nano urea could work efficiently under adequate soil nitrogen and it could not compensate the yields when soil application was curtailed to 50%.

Nitrogen-use efficiency and production economics

The partial factor productivity of nitrogen (PFP_N) was significantly impacted by various nitrogen scheduling treatments (Table 3). The highest PFP_N was obtained in the treatment T₁₁ (50% RDN + 2 sprays of nano urea at

Table 2. Yield attributes and yields of wheat as influenced by nano urea (pooled data of 2 years)

| Treatment | No. of spikes/m ² | No. of grains/spike | Spike length (cm) | 1,000-grain weight (g) | Grain yield (kg/ha) | Straw yield (kg/ha) | Harvest index |
|--|------------------------------|---------------------|-------------------|------------------------|---------------------|---------------------|---------------|
| T ₁ , 100 % RDN + 2 water sprays at tillering and jointing | 292 | 42.7 | 11.08 | 40.2 | 5048 | 7218 | 0.41 |
| T ₂ , 100 % RDN + single spray of nano urea at tillering | 304 | 43 | 11.23 | 40.2 | 5255 | 7620 | 0.41 |
| T ₃ , 100 % RDN + 2 sprays of nano urea at tillering and jointing | 310 | 46.1 | 11.68 | 40.3 | 5759 | 8524 | 0.40 |
| T ₄ , 100 % RDN + 2 sprays of urea (5%) at tillering and jointing | 320 | 46.3 | 11.75 | 40.5 | 5985 | 8798 | 0.40 |
| T ₅ , 75 % RDN + 2 water sprays at tillering and jointing | 280 | 41.9 | 10.99 | 39.9 | 4681 | 7022 | 0.40 |
| T ₆ , 75 % RDN + single spray of nano urea at tillering | 285 | 42.1 | 11.00 | 40.0 | 4799 | 7295 | 0.40 |
| T ₇ , 75 % RDN + 2 sprays of nano urea at tillering and jointing | 290 | 42.8 | 11.17 | 40.0 | 4965 | 7596 | 0.40 |
| T ₈ , 75 % RDN + 2 sprays of urea (5%) at tillering and jointing | 298 | 45.8 | 11.57 | 40.2 | 5487 | 8449 | 0.39 |
| T ₉ , 50 % RDN + 2 water sprays at tillering and jointing | 252 | 39.9 | 10.90 | 39.7 | 3992 | 6267 | 0.39 |
| T ₁₀ , 50 % RDN + single spray of nano urea at tillering | 255 | 40.3 | 10.95 | 39.7 | 4080 | 6568 | 0.38 |
| T ₁₁ , 50 % RDN + 2 sprays of nano urea at tillering and jointing | 262 | 40.9 | 11.00 | 39.8 | 4265 | 6909 | 0.38 |
| T ₁₂ , 50 % RDN + 2 sprays of urea (5%) at tillering and jointing | 270 | 41.0 | 11.15 | 39.8 | 4406 | 7049 | 0.38 |
| T ₁₃ , Control (No N application) | 202 | 32.7 | 10.28 | 36.7 | 2424 | 4170 | 0.37 |
| SEm± | 7.88 | 1.30 | 0.06 | 0.42 | 160.5 | 174.1 | 0.03 |
| CD (P=0.05) | 23.1 | 3.8 | 0.17 | 1.22 | 470.2 | 510.1 | NS |

RDN, Recommended dose of nitrogen; NS, Non-significant

Table 3. Nitrogen-use efficiencies and production economics of wheat as influenced by nano urea (pooled data of 2 years)

| Treatments | NUE indices | | Production economics | | | |
|--|---|-----------------------------|----------------------------------|---------------------------|-------------------------|------|
| | PFP _N (kg grain/ kg N) | ANUE (kg grain/ kg N) | Cost of cultivation (₹/ha) | Gross return (₹/ha) | Net return (₹/ha) | B:C |
| T ₁ , 100 % RDN + 2 water sprays at tillering and jointing | 33.65 | 17.49 | 43,950 | 95,903 | 51,953 | 2.18 |
| T ₂ , 100 % RDN + single spray of nano urea at tillering | 35.02 | 18.86 | 44,264 | 99,844 | 55,580 | 2.26 |
| T ₃ , 100 % RDN + 2 sprays of nano urea at tillering and jointing | 38.36 | 22.21 | 45,678 | 1,09,426 | 63,748 | 2.40 |
| T ₄ , 100 % RDN + 2 sprays of urea (5%) at tillering and jointing | 37.32 | 22.21 | 44,107 | 1,13,715 | 69,608 | 2.58 |
| T ₅ , 75 % RDN + 2 water sprays at tillering and jointing | 41.61 | 20.06 | 43,372 | 88,940 | 45,568 | 2.05 |
| T ₆ , 75 % RDN + single spray of nano urea at tillering | 42.63 | 21.10 | 43,686 | 91,189 | 47,503 | 2.09 |
| T ₇ , 75 % RDN + 2 sprays of nano urea at tillering and jointing | 44.08 | 22.56 | 45,100 | 94,331 | 49,231 | 2.09 |
| T ₈ , 75 % RDN + 2 sprays of urea (5%) at tillering and jointing | 44.66 | 22.93 | 43,530 | 1,04,246 | 60,716 | 2.39 |
| T ₉ , 50 % RDN + 2 water sprays at tillering and jointing | 53.22 | 20.90 | 42,795 | 75,843 | 33,048 | 1.77 |
| T ₁₀ , 50 % RDN + single spray of nano urea at tillering | 54.34 | 22.06 | 43,109 | 77,516 | 34,407 | 1.80 |
| T ₁₁ , 50 % RDN + 2 sprays of nano urea at tillering and jointing | 56.76 | 24.50 | 44,523 | 81,033 | 36,510 | 1.82 |
| T ₁₂ , 50 % RDN + 2 sprays of urea (5%) at tillering and jointing | 51.62 | 23.22 | 42,952 | 83,711 | 40,759 | 1.95 |
| T ₁₃ , Control (No N application) | - | - | 40,540 | 46,059 | 5,519 | 1.14 |
| SEm(±) | 1.84 | 0.68 | - | 4,949 | 4,949 | 0.04 |
| CD (P=0.05) | 5.38 | 1.98 | - | 14,502 | 14,502 | 0.13 |

RDN, Recommended dose of nitrogen; NUE, nitrogen use efficiency; ANUE, Agronomic nitrogen use efficiency; PFP_N, partial factor productivity of nitrogen

tillering and jointing (56.76 kg grain/kg N) which was followed by T₁₀ (54.34 kg grain/kg of N). It was noted that 100% RDN + 2 sprays of nano urea at tillering and jointing stages recorded much lower values of PFP_N (38.36 kg grain/kg N) despite being the higher yielder. The quantity of soil applied nitrogen in 50% RDN treatments (T₉-T₁₂) was curtailed to 75 kg/ha. As PFP_N is the proportion of yield and N added, the values were much higher in these treatments. Again, the quantity of nitrogen added through nano urea was practically negligible as it contains only 4% (v/v) nitrogen. With such a low quantity of added nitrogen, yield response was quite good. That's why nano urea spray twice significantly increased PFP_N for each level of N application (50%, 75%, or 100%), showing better NUE even than urea foliar application. The data further revealed that 75% RDN + 2 sprays of urea (5%) at tillering and jointing recorded the highest ANUE (24.93 kg grain/kg N). Higher ANUE was due to minimum application, controlled release, and reduced losses of urea foliar application rather than soil application. As the ANUE represents the proportionate yield enhancement over control, the values were slightly higher under urea foliar application rather than nano urea, being statistically *at par* with each other. In general, the NUE indices were higher under lower soil application treatments due to such huge curtailment in N application. Nano urea particles can easily penetrate through cell wall and reach upto plasma membrane and they also can penetrate through stomatal pores. These are also translocated through phloem to other plant parts and metabolically assimilated as per need of the plant (Kumar

et al., 2021a). Precise and targeted application through foliar spraying reduces urea losses and results in better crop harvest with lesser N application leading to higher nitrogen-use efficiency (Kumar *et al.*, 2020; Lahari *et al.*, 2021). Synchronising the nutrient availability as per need of the crop also helped to improve nutrient use efficiency (Mitra *et al.*, 2019).

The nano-urea treatments had slightly higher total cost of cultivation over urea foliar application. Among the treatments, 100% RD + 2 sprays of urea (5%) at tillering and jointing recorded significantly higher net returns (69608 / ha) and benefit: cost (B : C) (2.58). It was followed by 100% RD + 2 sprays of nano urea at tillering and jointing which registered a net return of 63748/ha with a B: C of 2.40. Due to higher yields obtained under these two treatments as compared to extra cost involvement, it recorded higher net returns and B:C ratio over the other treatments.

Foliar application of nano urea (liquid) twice at tillering and jointing stage had promotive effects on yields of wheat; however, there were no significant differences in grain yield of wheat with twice foliar application of nano urea and 5% urea when it was applied with 100% RDN. Twice application of nano urea proved better than single application in terms of productivity and nitrogen use efficiency. However, foliar application of nano urea or urea could not compensate the yield reduction under 50% RDN in wheat.

It can be concluded from this two-year study that nano urea had promotive effects on yields when it was applied with 100% N, quite similar to urea foliar application; but

simply foliar application of nano urea or urea could not compensate the yield reduction under 50–75% RDN in wheat.

REFERENCES

- Abebe, T.G., Tamtam, M.R., Abebe, A.A., Abtemariam, K.A., Shigut, T.G., Dejen, Y.A. and Haile, E.G. 2022. Growing use and impacts of chemical fertilizers and assessing alternative organic fertilizer sources in Ethiopia. *Applied and Environmental Soil Science* **14**: 4738416 <https://doi.org/10.1155/2022/4738416>
- Ahmed, S.S. and Fahmy, A.H. 2017. Environmental impact for applications of neem cake coated urea and nano iron foliar on rationalization of chemical nitrogen fertilizers and wheat yield. *Journal of Soil Science and Agriculture Engineering, Mansoura University* **8**(11): 613–620.
- Al-Juthery, H. W., Habeeb, K. H., Altaee, F.J.K., AL-Taey, D. K. and Al-Tawaha, A. R. M. 2018. Effect of foliar application of different sources of nano-fertilizers on growth and yield of wheat. *Bioscience research* (4): 3976–3985.
- Al-Juthery, H.W., Hardan, H.M., Swedi, F.G.A., Obaid, M. H. and Shami, Q. M. N.A. 2019. Effect of foliar nutrition of nano fertilizers and amino acids on growth and yield of wheat (*Triticum aestivum* L.). *Earth and Environmental Science*. <http://doi: 10.1088/1755-1315/388/1/012046>.
- Al-Juthery, H.W., Lahmod, N.R. and Al-Taee, R.A. 2021. Intelligent, Nano-fertilizers: A new technology for improvement nutrient use efficiency. *Earth and Environmental Science* **735**: 012086. <https://doi.org/10.1088/1755-1315/735/1/012086>
- Bakhtiari, M., Moaveni, P. and Sani, B. 2015. The effect of iron nano particles spraying time and concentration on wheat (*Triticum aestivum* L.). *Biological Forum – An International Journal* **7**(1): 679–683.
- Bartolucci, B., Scognamiglio, V., Antonacci, A. and Fraceto, L.F. 2022. What makes nanotechnologies applied to agriculture green? *Nano Today* **43**: 1–5. <https://doi.org/10.1016/j.nantod.2022.101389>
- Dapkekar, A., Deshpande, P., Manoj, D., Kishore, M. and Rajwade, J. 2018. Zinc use efficiency is enhanced in wheat (*Triticum aestivum* L.) through nano fertilization. *Scientific Reports* <http://doi: 10.1038/s41598-018-25247-5>.
- Dobermann, A. 2007. Nutrient use efficiency measurement and management. (In) Proceedings of International Fertilizer Industry Association Workshop on Fertilizer Best management Practices, 7–9 March, 2007, Brussels, 1–28.
- Ehsan, M., Raja, N.I., Mashwani, Z.R., Ikram, M. and Zohra, E. 2021. Responses of bimetallic Ag/ZnO alloy nano particles and urea on morphological and physiological attributes of wheat (*Triticum aestivum* L.). *IET Nanobiotechnology*. <http://doi: 10.1049/nbt2.12048>.
- Iqbal, M.A. 2020. Nano-fertilizers for sustainable crop production under changing climate: a global perspective. *Sustainable Crop Production* <https://doi.org/10.5772/intechopen.89089>
- Jyothi, T.V. and Hebsur, N.S. 2017. Effect of nano fertilizers on growth and yield of selected cereals - A review. *Agricultural Reviews* **38**(2): 112–120.
- Kiran, K. and Samal, K.C. 2021. 'Nano Urea Liquid'—A boon for Indian farmers and mother Earth. *Biotica Research Today* **3**(6): 511–514.
- Kumar, Y., Singh, T., Raliya, R. and Tiwari, K.N. 2021a. Nano fertilizers for sustainable crop production, higher nutrient use efficiency and enhanced profitability. *Indian Journal of Fertilizers* **17**: 1206–1214.
- Kumar, Y., Tiwari, K.N., Nayak, R.K., Rai, A., Singh, S.P., Singh, A.N., Kumar, Y., Tomar, H., Singh, T. and Raliya, R. 2020. Nano fertilizers for enhancing nutrient use efficiency, crop productivity and economic returns in winter season crops of Uttar Pradesh. *Indian Journal of Fertilizers* **16**: 772–786.
- Kumar, Y., Tiwari, K.N., Singh, T. and Raliya, R. 2021b. Nanofertilizers and their role in sustainable agriculture. *Annals of Plant and Soil Research* **23**(3): 238–255.
- Lahari, S., Hussain, S.A., Parameswari, Y.S. and Sharma, K.H.S. 2021. Grain yield and nutrient uptake of rice as influenced by the nano forms of nitrogen and zinc. *International Journal of Environment and Climate Change* **11**(7): 1–6.
- Mahmud, K., Panday, D., Mergoum, A and Missaoui, A. 2021. Nitrogen losses and potential mitigation strategies for a sustainable agroecosystem. *Sustainability* **13**: 2400. <https://doi.org/10.3390/su13042400>
- Martínez, A.M., Sánchez, E., Lorena, Trillo, L.P. and Álvarez, S.P. 2020. Impact of the foliar application of magnesium nano fertilizer on fertilizer on physiological and biochemical parameters and yield in green beans. *Notulae Botanicae Horti Agrobotanici Cluj-Napoca* **48**(4): 2167–2181.
- Mehta, S. and Bharat, R. 2019. Effect of integrated use of nano and non-nano fertilizers on yield and yield attributes of wheat (*Triticum aestivum* L.). *International Journal of Current Microbiology and Applied Science* **8**(12): 598–606.
- Mitra, B., Majumdar, K., Dutta, S.K., Mondal, T., Das, S., Banerjee, H., Ray, K. and Satyanarayana, T. 2019. Nutrient management in wheat (*Triticum aestivum*) production system under conventional and zero tillage in eastern sub-Himalayan plains of India. *Indian Journal of Agricultural Sciences* **89**(5): 775–784.
- Mitra, B., Singha, P., Roy Chowdhury, A., Sinha, A.K., Skalicky, M., Brestic, M., Alamri, S. and Hossain, A. 2023a. Optical sensor-based nitrogen management: An environmentally friendly and cost-effective approach for sustainable wheat (*Triticum aestivum* L.) production on eastern plains of India. *Frontiers in Sustainable Food Systems* **7**: 1153575.
- Mitra, B., Singha, P., Roy Chowdhury, A., Sinha, A.K., Skalicky, M., Brestic, M., Alamri, S. and Hossain, A. 2023b. Normalized difference vegetation index sensor-based nitrogen management in bread wheat (*Triticum aestivum* L.): Nutrient uptake, use efficiency, and partial nutrient balance. *Frontiers in Plant Science* **14**: 1153500.
- Mondal, T., Mitra, B. and Das, S. 2018. Precision nutrient management in wheat (*Triticum aestivum* L.) using Nutrient Expert: Growth phenology, yield, nitrogen-use efficiency and profitability under eastern sub-Himalayan plains. *Indian Journal of Agronomy* **63**(2): 174–180.
- Pachauri, R.K. and Meyer, L.A. 2014. Contribution of Working Groups I, II and III to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change, Core Writing Team, IPCC, Geneva, Switzerland. P 151.
- Preetha, P.S. and Balakrishnan, N. 2017. A review of nano fertilizers and their use and functions in soil. *International Journal of Current Microbiology and Applied Sciences* **6**: 3117–3133.
- Raliya, R., Saharan, V., Dimpka, C. and Biswas, P. 2018. Nanofertilizer for precision and sustainable agriculture:

- current state and future perspectives. *Journal of Agricultural and Food Chemistry* **66**: 6487–6503. <https://doi.org/10.1021/acs.jafc.7b02178>
- Saurabh, K., Manjaiah, K.M., Datta, S.C., Thekkumpurath, A.S. and Kumar, R. 2019. Nano clay polymer composites loaded with urea and nitrification inhibitors for controlling nitrification in soil. *Archives of Agronomy and Soil Science* **65**: 478–491.
- Singha, P. and Mitra, B. 2020. Nitrogen scheduling in wheat (*Triticum aestivum* L.) using a NDVI sensor under sub-Himalayan plains of West Bengal. *Journal of Crop and Weed* **16**(3): 49–55.
- Upadhyay, P.K., Dey, A., Singh, V.K. Dwivedi, B.S., Singh, T., Rajanna, G.A., Babu, S., Rathore, S.S., Singh, R.K., Shekhawat, K., Rangot, M., Kumar, P., Yadav, D., Singh, D.P., Dasgupta, D. and Shukla, G. 2023. Conjoint application of nano-urea with conventional fertilizers: an energy efficient and environmentally robust approach for sustainable crop production. *PLoS ONE* **18**(7): e0284009

Efficiency of different incubating material for phosphate rich organic manure in wheat (*Triticum aestivum*)

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ABSTRACT

A field experiment was conducted at Centre for Research on Integrated Farming Systems, Sardarkrushinagar Dantiwada Agricultural University, Sardarkrushinagar during 2018–19 to 2020–21 to study the efficiency of different incubating material for phosphate rich organic manure (PROM) in wheat. A total of fourteen treatments such as T₁: Control, T₂: DAP @ 60 kg P₂O₅/ha, T₃: Rock phosphate @ 40 kg P₂O₅/ha incubated with vermicompost, T₄: Rock phosphate @ 60 kg P₂O₅/ha incubated with vermicompost, T₅: Rock phosphate @ 40 kg P₂O₅/ha incubated with FYM, T₆: Rock phosphate @ 60 kg P₂O₅/ha incubated with FYM, T₇: Rock phosphate @ 40 kg P₂O₅/ha incubated with compost, T₈: Rock phosphate @ 60 kg P₂O₅/ha incubated with compost, T₉: Rock phosphate @ 40 kg P₂O₅/ha incubated with vegetable waste, T₁₀: Rock phosphate @ 60 kg P₂O₅/ha incubated with vegetable waste, T₁₁: Rock phosphate @ 40 kg P₂O₅/ha incubated with green algae, T₁₂: Rock phosphate @ 60 kg P₂O₅/ha incubated with green algae, T₁₃: Rock phosphate @ 40 kg P₂O₅/ha incubated with cow urine and T₁₄: Rock phosphate @ 60 kg P₂O₅/ha incubated with cow urine were evaluated based on growth parameters, yield attributes and yield. The pooled result of three years experiment indicated that phosphorus source of DAP in wheat (60 kg P₂O₅/ha) can be replaced with Udaipur rock phosphate (31% P₂O₅) @ 198 kg/ha incubated for 30 days with FYM or vermicompost or compost or vegetable waste (each of 593 kg) or cow urine (593 L) in the ratio of 1:3 ratio as basal for obtaining higher yield and net returns.

Key words: Cow urine, Farm Yard Manure, Green algae and Vermicompost

Wheat is the second most important crop in India and a principal source of calorie intake. It has been under cultivation in the Indian subcontinent from pre-historic times and is an integral part of the country's economy and food security. Systematic research in the crop has started in India way back in 1960s through the coordinated system of multi-location research to cater the needs of diverse population. The country achieved rapid strides in wheat production during the last four decades resulting in self-sufficiency and surplus production. This has enabled the country to meet domestic demand from its own production and reduce dependence on wheat imports. In 1978, for the first time in the post-independence period, India emerged as a net exporter of wheat (Chand, 2001). However, feeding burgeoning population through the next 25 years remains

an uphill task. Increasing domestic and international demand owing to population growth should meet the future challenges of food and nutritional security. The country will have to feed about 1.30 billion people by 2020 requiring 5–6 million tons of additional food grains every year. India by 2030, will require approximately 100 million tons of wheat to cover an estimated demand of 345 million tons of food grains (Annual Report, 2011–12). The country as per the national policy on agriculture has set a target of 4 per cent growth rate for which high growth in wheat production becomes a mandate owing to its importance in food basket. The growth rate can be achieved by increasing the production and bridging the existing yield gap. Regional surveys reveal large variation in yield across research farm, farmers and fields attributed to management, site and season differences. Punjab and Haryana recorded 4.3 and 4.2 t/ha, respectively in wheat production and the yield gap between farm and potential yield was about 45 and 35 per cent, respectively in those states (Fischer, 2009). Bhattacharya (2011) estimated 28.22 per cent yield gap I (difference between potential yield and national average yield) in India and 57.01 per cent yield gap II (difference

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between potential yield and state average yield) and 0.98 per cent yield gap III (difference between potential yield and on-farm yield) in Uttar Pradesh. Aggarwal *et al.* (2008) found that wheat registered a yield gap of 70 kg/ha between research farm and farmer's field.

Phosphorus (P) fertilizers are critical to crop production and global food security. Strengthening intensive agricultural production will also increase the demand for P fertilizers. China produces and consumes 34.0% and 22.5% of global P fertilizer. The output of high-concentration P fertilizer accounts for 95.9% of the total P fertilizer production, mainly as ammonium P fertilizer. However, the P supply capacity of different soils varies significantly due to soil properties, P fractions and P fertilizer types, resulting in different soil types requiring different P fertilizer types. In calcareous soils, due to the high content of calcium carbonate in the soil, the fixation effect of calcium carbonate on P is the main factor. In contrast, P is mainly fixed by a large amount of amorphous iron oxide and alumina in acid soils. From this, P fertilizer is easily fixed and accumulated after being applied to the soil. As a result, the availability is reduced, resulting in the average in-season P use efficiency (PUE) being 3.0–21.2%. (Meyer *et al.*, 2020) In addition, to maximize the effectiveness of all P fertilizer types, corresponding fertilization measures should be taken according to the characteristics of different P fertilizer types. Therefore, strategies are needed to improve fertilizer PUE by matching the soil types—P fertilizer type—cropping system in P nutrient management. Phosphorus deficiency can be corrected by applying phosphatic fertilizers, but recovery of applied P is notoriously low due to its rapid conversion to sparingly soluble compounds in soils. Rock phosphate is a raw material for phosphatic fertilizer industry. Several reports have shown that some species such as wheat, oil seed crops and legumes are particularly efficient in using P from rock phosphate through the release of H⁺ (Salim *et al.*, 2013). In the present study a rock phosphate incubated with different organic media was used to identify the best inoculated media under P-limiting conditions, against their P utilization efficiencies from rock phosphate.

MATERIALS AND METHODS

A field experiment was conducted at Centre for Research on Integrated Farming Systems, S. D. Agricultural University, Sardarkrushinagar, Gujarat, India, during *rabi* season of 2018-19 to 2020-21 to study the different incubating material for Phosphorus Rich Organic Manure (PROM) in wheat. The experimental soil was loamy sand in texture, alkaline in reaction (pH 7.76), 0.310% organic carbon, 146 kg/ha available nitrogen and 31 kg/ha P₂O₅ and 226 kg/ha K₂O. Total fourteen treatments with different source were used, namely *viz.*, T₁: Control, T₂: DAP @

60 kg P₂O₅/ha, T₃: Rock phosphate @ 40 kg P₂O₅/ha incubated with vermicompost, T₄: Rock phosphate @ 60 kg P₂O₅/ha incubated with vermicompost, T₅: Rock phosphate @ 40 kg P₂O₅/ha incubated with FYM, T₆: Rock phosphate @ 60 kg P₂O₅/ha incubated with FYM, T₇: Rock phosphate @ 40 kg P₂O₅/ha incubated with compost, T₈: Rock phosphate @ 60 kg P₂O₅/ha incubated with compost, T₉: Rock phosphate @ 40 kg P₂O₅/ha incubated with vegetable waste, T₁₀: Rock phosphate @ 60 kg P₂O₅/ha incubated with vegetable waste, T₁₁: Rock phosphate @ 40 kg P₂O₅/ha incubated with green algae, T₁₂: Rock phosphate @ 60 kg P₂O₅/ha incubated with green algae, T₁₃: Rock phosphate @ 40 kg P₂O₅/ha incubated with cow urine and T₁₄: Rock phosphate @ 60 kg P₂O₅/ha incubated with cow urine were tried in randomized block design with three replications on fixed site. *Rabi* wheat seeds was treated with *Azotobacter* @5 ml/kg seed. Common dose of 120 kg/ha nitrogen was applied for all treatments except T₁.

Udaipur rock phosphate (URP, 31%) used for the experiment was grained and sieved to get size of 74 micron before incubation. After that, these grained Udaipur rock phosphate was incubated with FYM/vermicompost/compost/green algae and vegetable waste with the ratio of 1:3 (W/W) and with cow urine (1:3 W/V) for the period of 30 days before application under shade. Watering was done twice in the day and stopped 4 days before using it. This incubated rock phosphate was applied as basal dose to fulfill the requirement of phosphorus. In case of cow urine, incubated material was mixed with sand for easy application at the time of sowing. The representative soil samples were collected and analyzed for organic carbon, available nitrogen, phosphorus and potassium after completion of crop sequence. The cost of cultivation was calculated based on existing input cost. Net return was calculated by subtracting cost of cultivation from gross income of system. The benefit: cost ratio (BCR) was worked out dividing net return by the cost of cultivation. No severe pests and diseases were observed during the crop growth; however, necessary plant protection measures were taken on need basis.

RESULTS AND DISCUSSION

An experiment was conducted during *rabi* seasons of 2018-19 to 2020-2021 at Centre for Research on Integrated Farming Systems, Sardarkrushinagar to study the different incubating material for phosphate rich organic manure (PROM) in wheat. The result and discussion is described on the pooled data of three years.

The plant population found non-significant under different treatments. The data on periodical plant height of wheat as influenced by incubating material of phosphate rich organic manure (PROM) were recorded at 30, 60 DAS and

Table 1. Chemical composition of high-grade Udaipur rock phosphate before incubation

| Sr. no. | Parameters | URP (31%) |
|---------|------------------------------------|-----------|
| 1 | P ₂ O ₅ (%) | 31.3 |
| 2 | Ca O (%) | 46.0 |
| 3 | Mg O (%) | 1.4 |
| 4 | R ₂ O ₃ *(%) | 1.6 |
| 5 | L.O.I. ** (%) | 5.5 |
| 6 | AI *** (%) | - |
| 7 | Particle size | 74 micron |

* R₂O₃-Fe₂O₃+Al₂O₃+Cr₂O₃+Other oxides (Source: Soni and Aery, 2002. RSMMLtd, UDR)

** L.O.I.-Loss on Ignition

*** AI-Acid in soluble

90 DAS are presented in the Table 2. Increase in plant height was rather slow up to 30 DAS, thereafter; it increased linearly up to 90 DAS. Different incubating material for PROM was fails to exert its significant effect on plant height at 30 DAS, but application of DAP @ 60 kg P₂O₅/ha (T₂) recorded significantly highest plant height (54.4 cm) at 60 DAS. At 90 DAS, treatment T₂ recorded significantly higher plant height (70.0 cm), which was at par with T₆, T₁₀ and T₁₄. Number of tillers, spike length, number of grain per ear head recorded significantly higher under application of DAP @ 60 kg P₂O₅/ha (T₂), which was found at par with T₄, T₆, T₈, T₁₀, T₁₂ and T₁₄. Data presented in the Table 2 indicated that different incubating material PROM exhibited their significant influence on test weight. An application of DAP @ 60 kg P₂O₅/ha (T₂) reg-

istered significantly higher test weight (38.50 g), which was at par with T₄, T₅, T₆, T₇, T₈, T₁₀, T₁₂ and T₁₄. This was due to higher phosphorus availability near root zone area which increased number of tillers and effective tillers per meter row length. The results are in close conformity with the findings of Ditta *et al.* (2015), Rajew *et al.* (2018) and Chaudhari *et al.* (2019).

The data presented in Table 3 revealed that wheat grain yield was significantly affected due to different incubating material for PROM during individual years and also in pooled results. Significantly the higher grain yield and straw yield of 4,411 kg/ha and 5595 kg/ha, respectively were recorded under application of DAP @ 60 kg P₂O₅/ha (T₂) over different incubating material for PROM, which was at par with T₄ (4032 kg/ha and 5131 kg/ha) and T₆ (4,121 kg/ha and 5325 kg/ha), T₈ (3,863 kg/ha and 4860 kg/ha), T₁₀ (3873 kg/ha and 4,950 kg/ha) and T₁₄ (3807 kg/ha and 4905 kg/ha), respectively. Whereas, significantly the lowest grain yield of 2,044 kg/ha and 2465 kg/ha were observed under control (T₁). Significantly the higher gross profit (99,411 ₹/ha) was registered application of DAP @ 60 kg P₂O₅/ha (T₂) over different incubating material for PROM, which was at par with T₄ (90,909 ₹/ha), T₆ (93,072 ₹/ha), T₈ (86978 ₹/ha), T₁₀ (87361 ₹/ha) and T₁₄ (85947 ₹/ha). Whereas, significantly the lowest gross profit of 45813 ₹/ha were recorded under control (T₁). Same trend was observed for net profit. Significantly the higher net profit was registered with T₂ (58,690 ₹/ha) over different incubating material, which was at par with T₄ (48,907 ₹/ha), T₆ (48,907 ₹/ha), T₈ (53,737 ₹/ha), T₁₀ (48,236 ₹/ha), T₁₂ (48,236 ₹/ha), T₁₄ (48,236 ₹/ha), T₁₀

Table 2. Effect of different incubating material for PROM on growth and yield attributing characters of wheat. (Pooled of 3 years)

| Treatments | Plant population at initial (metre row length) | Plant height (cm) at 30 DAS | Plant height (cm) at 60 DAS | Plant height (cm) at 90 DAS | Number of tillers (No.) | Spike length (cm) | Number of grains/spike | Test weight (g) |
|-----------------|--|-----------------------------|-----------------------------|-----------------------------|-------------------------|-------------------|------------------------|-----------------|
| T ₁ | 31.5 | 15.0 | 34.9 | 49.5 | 52.2 | 4.58 | 29.8 | 29.5 |
| T ₂ | 32.6 | 20.4 | 54.4 | 70.0 | 81.7 | 8.02 | 42.8 | 38.5 |
| T ₃ | 31.4 | 15.0 | 41.7 | 60.5 | 66.2 | 6.41 | 37.7 | 35.9 |
| T ₄ | 31.8 | 15.7 | 44.4 | 66.0 | 75.9 | 7.16 | 40.0 | 37.7 |
| T ₅ | 31.6 | 15.3 | 43.0 | 61.6 | 70.5 | 6.94 | 38.4 | 36.6 |
| T ₆ | 32.0 | 16.0 | 46.2 | 67.2 | 76.8 | 7.62 | 41.3 | 37.9 |
| T ₇ | 31.2 | 15.2 | 42.3 | 62.6 | 68.0 | 6.58 | 37.0 | 36.6 |
| T ₈ | 31.6 | 15.9 | 44.5 | 64.9 | 73.3 | 7.18 | 39.0 | 37.8 |
| T ₉ | 32.0 | 15.3 | 42.8 | 62.9 | 70.2 | 6.69 | 38.7 | 35.9 |
| T ₁₀ | 31.6 | 15.8 | 45.3 | 68.3 | 73.2 | 7.19 | 39.5 | 37.4 |
| T ₁₁ | 31.1 | 15.1 | 41.1 | 57.2 | 68.4 | 6.62 | 37.6 | 34.8 |
| T ₁₂ | 31.7 | 15.7 | 44.1 | 64.6 | 74.7 | 7.05 | 39.4 | 36.5 |
| T ₁₃ | 31.4 | 15.3 | 43.5 | 62.5 | 72.0 | 6.67 | 38.2 | 35.4 |
| T ₁₄ | 31.4 | 16.7 | 47.0 | 68.6 | 78.7 | 7.50 | 42.0 | 38.2 |
| S.Em.± | 0.447 | 0.47 | 1.32 | 1.75 | 3.06 | 0.36 | 1.24 | 0.69 |
| CD at 5 % | NS | NS | 3.71 | 4.95 | 8.90 | 1.04 | 3.60 | 2.01 |
| CV % | 4.68 | 8.89 | 8.98 | 8.32 | 7.75 | 8.26 | 7.27 | 3.98 |

Table 3. Effect of different incubating material for PROM on yield and economics of wheat. (Pooled of 3 years)

| Treatment | Grain yield (kg/ha) | Straw yield (kg/ha) | Gross return (₹/ha) | Cost of Cultivation (₹/ha) | Net return (₹/ha) | BCR |
|-----------------|---------------------|---------------------|---------------------|----------------------------|-------------------|------|
| T ₁ | 2,044 | 2,465 | 45,813 | 36,031 | 9,782 | 1.27 |
| T ₂ | 4,411 | 5,595 | 99,411 | 40,721 | 58,690 | 2.44 |
| T ₃ | 3,341 | 4,251 | 75,328 | 40,523 | 34,806 | 1.86 |
| T ₄ | 4,032 | 5,131 | 90,909 | 42,001 | 48,907 | 2.16 |
| T ₅ | 3,416 | 4,444 | 77,198 | 38,745 | 38,453 | 1.99 |
| T ₆ | 4,121 | 5,325 | 93,072 | 39,335 | 53,737 | 2.37 |
| T ₇ | 3,160 | 4,126 | 71,441 | 38,350 | 33,091 | 1.86 |
| T ₈ | 3,863 | 4,860 | 86,978 | 38,742 | 48,236 | 2.25 |
| T ₉ | 3,484 | 4,464 | 78,604 | 40,128 | 38,476 | 1.96 |
| T ₁₀ | 3,873 | 4,950 | 87,361 | 41,409 | 45,952 | 2.11 |
| T ₁₁ | 3,141 | 4,123 | 71,060 | 40,128 | 30,932 | 1.77 |
| T ₁₂ | 3,436 | 4,596 | 77,899 | 41,409 | 36,490 | 1.88 |
| T ₁₃ | 3,164 | 4,307 | 71,888 | 38,547 | 33,341 | 1.86 |
| T ₁₄ | 3,807 | 4,905 | 85,947 | 39,038 | 47,264 | 2.20 |
| SEm± | 209 | 268 | 4,679 | - | 4,679 | - |
| CD (P=0.05) | 609 | 779 | 13,605 | - | 13,605 | - |
| CV % | 13.09 | 12.35 | 12.52 | - | 24.96 | - |

BCR = Benefit cost ratio

(45,952 ₹/ha) and T₁₄ (47,264 ₹/ha), while highest BCR registered under with application of DAP @ 60 kg P₂O₅/ha (2.44) followed by T₆ (2.37), T₈ (2.25), T₁₄ (2.20) and T₁₀ (2.11) in pooled. It might be due to better nutritional environment for wheat under incubation of rock phosphate with FYM and vegetable waste, which had increased the solubility and availability of phosphorus from rock phosphate and yield attributes of wheat. The results are in close conformity with the findings of Shaktawat *et al.* (2004), Mamun *et al.* (2012), Vyas *et al.* (2013), Sarkar *et al.* (2018), Rajew *et al.* (2018) and Chaudhari *et al.* (2019).

Data presented in the Table 4 indicated that the mean

highest total nutrient uptake by the crop (109.5 nitrogen, 24.0 phosphorus and 99.2 potassium kg/ha) was recorded with the application of DAP @ 60 kg P₂O₅/ha followed by rock phosphate @ 60 kg P₂O₅/ha incubated with FYM (103.9, 22.5 and 96.0 kg/ha, respectively). Data presented in the Table 5 revealed that, significantly higher soil organic carbon (0.364%) was recorded with the application rock phosphate @ 60 kg P₂O₅/ha incubated FYM, which was at par with T₄, T₈, T₁₂, T₅, T₇, T₉, T₁₄ and T₁₃. In case of available nitrogen (154 kg/ha) and available potash (236 kg/ha) were recorded maximum with application of rock phosphate @ 60 kg P₂O₅/ha incubated with FYM and cow

Table 4. Effect of different incubating material for PROM on nutrient uptake (kg/ha) by wheat

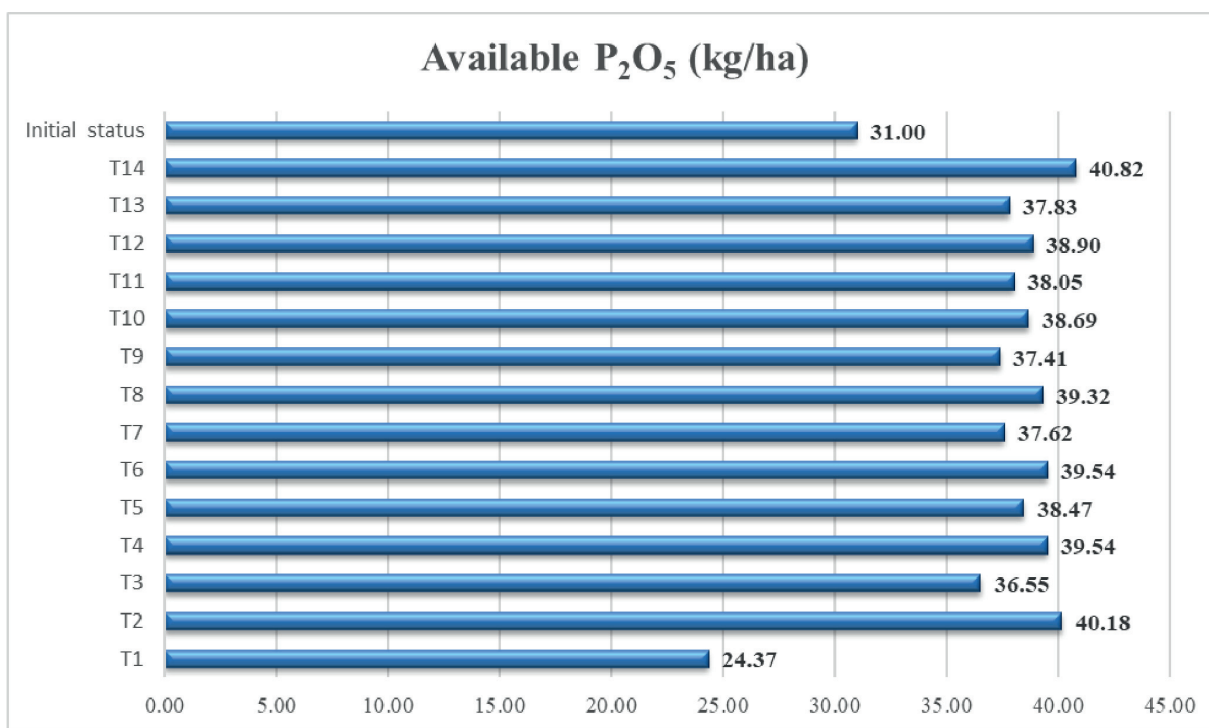
| Treatment | Grain uptake | | | Straw uptake | | | Total uptake | | |
|-----------------|--------------|-------|-------|--------------|-------|-------|--------------|-------|-------|
| | N | P | K | N | P | K | N | P | K |
| T ₁ | 37.09 | 6.47 | 12.63 | 12.99 | 3.27 | 31.31 | 50.08 | 9.74 | 43.94 |
| T ₂ | 79.68 | 15.41 | 27.17 | 29.83 | 8.60 | 72.01 | 109.51 | 24.01 | 99.18 |
| T ₃ | 60.99 | 11.14 | 20.72 | 22.26 | 5.88 | 54.56 | 83.25 | 17.02 | 75.28 |
| T ₄ | 73.63 | 14.29 | 24.97 | 27.28 | 7.89 | 67.21 | 100.91 | 22.18 | 92.18 |
| T ₅ | 62.63 | 11.60 | 21.35 | 23.30 | 6.25 | 58.69 | 85.93 | 17.85 | 80.04 |
| T ₆ | 75.84 | 14.52 | 25.86 | 28.05 | 8.03 | 70.16 | 103.89 | 22.55 | 96.02 |
| T ₇ | 58.29 | 10.94 | 19.75 | 20.88 | 5.85 | 55.18 | 79.17 | 16.79 | 74.93 |
| T ₈ | 71.26 | 13.76 | 24.56 | 24.36 | 7.49 | 65.47 | 95.62 | 21.25 | 90.03 |
| T ₉ | 64.41 | 11.88 | 22.12 | 23.54 | 6.45 | 60.24 | 87.95 | 18.33 | 82.36 |
| T ₁₀ | 71.07 | 13.46 | 24.15 | 26.22 | 7.58 | 68.20 | 97.29 | 21.04 | 92.35 |
| T ₁₁ | 57.31 | 10.42 | 19.40 | 21.94 | 5.85 | 56.20 | 79.25 | 16.27 | 75.60 |
| T ₁₂ | 60.95 | 11.81 | 20.53 | 24.52 | 7.10 | 63.94 | 85.47 | 18.91 | 84.47 |
| T ₁₃ | 57.06 | 11.10 | 19.83 | 23.22 | 6.48 | 60.72 | 80.28 | 17.58 | 80.55 |
| T ₁₄ | 69.70 | 13.54 | 23.53 | 25.00 | 7.78 | 65.92 | 94.70 | 21.32 | 89.45 |
| SEm± | 3.89 | 0.71 | 1.30 | 1.50 | 0.41 | 3.91 | 5.26 | 1.08 | 5.09 |
| CD (P=0.05) | 11.30 | 2.07 | 3.80 | 4.37 | 1.19 | 11.38 | 15.28 | 3.14 | 14.79 |
| CV % | 13.55 | 12.84 | 13.33 | 13.67 | 12.75 | 12.61 | 12.39 | 11.36 | 11.73 |

Table 5. Effect of different incubating material for PROM on soil fertility status after harvest

| Treatment | SOC (%) | Available nutrients (kg/ha) | | | pH | EC (dSm ⁻¹) |
|-----------------|---------|-----------------------------|-------------------------------|------------------|------|-------------------------|
| | | N | P ₂ O ₅ | K ₂ O | | |
| T ₁ | 0.252 | 127 | 24.37 | 224 | 7.78 | 0.138 |
| T ₂ | 0.308 | 147 | 40.18 | 224 | 7.61 | 0.140 |
| T ₃ | 0.336 | 148 | 36.55 | 227 | 7.63 | 0.138 |
| T ₄ | 0.357 | 154 | 39.54 | 236 | 7.71 | 0.140 |
| T ₅ | 0.343 | 149 | 38.47 | 227 | 7.73 | 0.138 |
| T ₆ | 0.364 | 152 | 39.54 | 233 | 7.73 | 0.134 |
| T ₇ | 0.329 | 149 | 37.62 | 224 | 7.80 | 0.132 |
| T ₈ | 0.357 | 153 | 39.32 | 233 | 7.61 | 0.133 |
| T ₉ | 0.329 | 149 | 37.41 | 230 | 7.44 | 0.136 |
| T ₁₀ | 0.336 | 151 | 38.69 | 230 | 7.45 | 0.132 |
| T ₁₁ | 0.308 | 147 | 38.05 | 227 | 7.59 | 0.137 |
| T ₁₂ | 0.35 | 151 | 38.9 | 230 | 7.56 | 0.137 |
| T ₁₃ | 0.322 | 150 | 37.83 | 230 | 7.46 | 0.133 |
| T ₁₄ | 0.343 | 154 | 40.82 | 233 | 7.45 | 0.135 |
| SEm± | 0.019 | 8.3 | 2.23 | 9.6 | 0.09 | 0.005 |
| CD (P=0.05) | 0.054 | NS | 6.49 | NS | 0.25 | NS |
| Initial status | 0.310 | 146 | 31.00 | 226 | 7.76 | 0.138 |
| CV % | 9.76 | 9.62 | 10.27 | 7.3 | 1.94 | 6.490 |

Rate of produce and inputs used in wheat

| | | | | | | | | |
|---|------------------------------|-------------|----|-----------------------|-------------|----|-----------------|----------|
| 1 | Selling price of wheat seed | ₹ 20/kg | 6 | Labour charge | ₹ 260/day | 11 | Compost | ₹ 0.5/kg |
| 2 | Selling price of wheat straw | ₹ 2/ kg | 7 | Chlorpyriphos | ₹ 450/litre | 12 | Green algae | ₹ 5/kg |
| 3 | Urea | ₹ 5.88/ kg | 8 | Rock phosphate (31 %) | ₹ 6/kg | 13 | Cow urine | ₹ 1/kg |
| 4 | DAP | ₹ 24/ kg | 9 | FYM | ₹ 1.5/kg | 14 | Vegetable waste | ₹ 5/kg |
| 5 | Pendimethalin | ₹ 540/litre | 10 | Vermicompost | ₹ 6/kg | | | |

**Fig. 1.** Effect of available phosphorus on initial soil status and different treatments.

urine, while available phosphorus was significantly higher with the application of rock phosphate @ 60 kg P₂O₅/ha incubated with cow urine (40.82 kg/ha), which was at par with treatment T₂ to T₁₃. Soil pH (7.44) was observed lowest under T₉, while EC (0.132 dS/m) was lowest under T₁₀.

It can be concluded that the diammonium phosphate (DAP) (60 kg P₂O₅/ha) can be replaced with Udaipur rock phosphate (31 per cent P₂O₅) @ 198 kg/ha incubated for 30 days with FYM or vermicompost or compost or vegetable waste (each of 593 kg) or cow urine (593 L) in the ratio of 1:3 for obtaining higher yield and net returns.

REFERENCES

- Aggarwal, P.K., Hebbar, K.B., Venugopalan, M.V., Rani, S., Bala, A., Biswal, A. and Wani, S.P. 2008. Quantification of yield gaps in rain-fed rice, wheat, cotton and mustard in India. Global Theme on Agro ecosystems Report No. 43. ICRISAT, Patancheru 502 324, Andhra Pradesh, India.
- Annual Report 2011–12. Directorate of wheat research, Karnal, Haryana.
- Bhattacharya, M. 2011. Economic analysis of yield gaps in principal crops in India. *Agricultural Situation in India* 8: 231–239.
- Chand, R., Kumar, P. and Kumar, S. 2011. Total factor productivity and contribution of research investment to agricultural growth in India, National Centre for Agricultural Economics and Policy Research, Policy Paper 25, March 2011.
- Chaudhari, H.L., Patel, A.M., Chaudhari, M.M., Patel, K.M. and Patel, S.A. 2019. Response of wheat to different PROMs and PSB under varying levels of phosphorus on yield and yield attributing characters. *Green Farming* 10(6): 718–721.
- Ditta, A., Arshad, M., Zahir, Z.A. and Jamil, A. 2015. Comparative efficacy of rock phosphate enriched organic fertilizer vs. mineral phosphatic fertilizer for nodulation, growth and yield of lentil. *International Journal of Agricultural Biology* 17: 589–595.
- Fischer, R.A., Derek, Byerlee and Edmeades, G.O. 2009. Can technology deliver on the yield challenge to 2050. Expert meeting on how to feed the world in 2050, Food and Agriculture Organization of the United Nations Economic and Social Development Department.
- Mamun, N.H., Rahman, S. Jahangir, N.M., Moula, M.S. and Islam, K.N. 2012. Effect of phosphate rock on the growth and yield of wheat (*Triticum aestivum* L.) under old Brahmaputra Floodplain soils. *The Agriculturists* 10: 31–37.
- Meyer, G., Bell, M.J., Doolette, C.L., Brunetti, G., Zhang, Y.Q., Lombi, E., Kopittke, P.M. 2022. Plant-Available Phosphorus in Highly Concentrated Fertilizer Bands: Effects of Soil Type, Phosphorus Form, and Coapplied Potassium. *Journal of Agricultural and Food Chemistry* 68: 7,571–7,580.
- Rajeev, K., Maya, K., Amit, B., Pandey, D., Singh, V. and Pradeep, R. 2018. Effect of rock phosphate with different acidulates on growth and yield of different field crops. *Indian Journal of Agronomy* 63(3): 293–299.
- Sarkar, S., Devi, N.S., Singh, A. and Longkumer, Y. 2018. Effect of single super phosphate and rock phosphate on growth and yield of rice. *Journal of Pharmacognosy and Phytochemistry* 7: 3,654–3,656.
- Shaktawat, M.S., Aery, N.C., Singh, M., Swami, B.N. and Katewa, M.K. 2004. Phosphate rich organic manure: an alternate to phosphatic fertilizers. Himanshu Publications (ED.) Udaipur. Pp. 13–18.
- Soni, P. and Aery, N.C. 2002. Agronomic effectiveness of high-grade rock phosphate with organic sources and phosphate solubilizing bacteria on wheat (*Triticum aestivum* L.). PROM Review, Phosphate Research and Development Centre, RSMM Limited, Udaipur, pp. 69–74.
- Vyas, K.G., Patel, A.M., Raval, C.H. and Bhatt, P.K. 2013. Effect of rock phosphate, FYM and phosphobacteria on growth, yield and economics of wheat in north Gujarat. *Madras Agricultural journal* 100: 477–79.
- Muhammad Masood Saleem, M.M., Arshad, M. and Yaseen, M. 2013. Effectiveness of Various Approaches to Use Rock Phosphate as a Potential Source of Plant Available P for Sustainable Wheat Production. *International Journal of Agriculture and Biology* 15(2): 223–230.

Selectivity of new generation herbicide ‘Tembotrione’ under conservation agriculture-based maize (*Zea mays*) in maize-wheat-mungbean cropping system

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ABSTRACT

An experiment was conducted at the ICAR-Indian Agricultural Research Institute in New Delhi during the rainy (*Kharif*) seasons of 2021–22 and 2022–23. The study aimed to evaluate the weed control efficiency of low dose new generation herbicide: tembotrione (34.4% SC) as a component of integrated weed management (IWM), on zero-till (ZT) and conventional till (CT) maize (*Zea mays* L.). The treatments were comprised of conventional tillage maize (M1: CT-M), conventional tillage maize with green manure from preceding green gram (M2: CT-M+GM), zero tillage maize with residue retention at 3 t/ha (M3: ZT-M+R), zero tillage maize with *Sesbania* co-culture as brown manuring (cover crop) (M4: ZT-M+BM) in the main plot and five weed control treatments, viz S1: Unweeded check, S2: Pre +1 HW, S3: Pre + Post (tembotrione) @120g/ha, S4: Pre+ Post (Premix of Mesotrione+ Atrazine) @120 g/ha, S5: Weed free check (WFC) in the sub-plots were evaluated in split-plot design. It was observed that ZT-M+BM caused a considerable reduction in the population of broad-leaf weed, narrow leaf weed with sedges and total weeds (28.4% reduction at 60 days after sowing) compared to M1. The results also revealed that the sequential application of atrazine @750g/ha+pendimethalin @750g/ha(pre) followed by (fb.) tembotrione (34.4% SC) @120 g/ha (post) among the herbicide options reduced the weeds population (78.5%) and dry weight (81.3%) significantly than the un-weeded control (UWC). Maize yield attributes were higher in ZT with *Sesbania* co-culture (ZT-M+BM) than conventional-tilled treatments (CT-M). The application of atrazine @750g/ha+pendimethalin @750g/ha (pre) fb. tembotrione @120 g/ha (post) combined with ZT-M+BM resulting in higher maize yield (6.88 t/ha) which was comparable with that in weed-free check (WFC). The post emergence (PoE) application of tembotrione (34.4% SC) @120 g/ha recorded highest weed control efficiency (86.2%), weed control index (88.1%) and lowest value of weed index (7.04) when applied in the ZT-maize with *sesbania* as a cover crop. Therefore, combining zero tillage (ZT) with brown manure (*Sesbania*), along with atrazine and pendimethalin (@750g/ha each) as pre-emergence herbicides, and tembotrione (@120g/ha) as a post-emergence herbicide is recommended for effective weed control and high maize productivity in the North-Western Indo-Gangetic plains (IGP).

Key words: Brown manuring, Cover, Conservation agriculture, Crop, HPPD-inhibitor, Integrated weed management, Tembotrione

The global adoption of conservation agriculture (CA) aims for sustainable crop production systems to feed the worlds growing population (8 billion) and enhance ecosystem services (Giller *et al.*, 2015). CA faces challenges in crop establishment and weed management, especially under zero tillage (ZT) due to surface residue issues in early conversion years (1 to 3 years) (Soni *et al.*, 2020). Integrating diverse cropping systems, advanced weed management

techniques with new generation herbicides, and improving the crop establishment methods are crucial for CA-based maize (*Zea mays* L.) cultivation. The continuous rice-wheat system (RWS) also faces weed shift issues, particularly small canary grass (*Phalaris minor*) in wheat and Bermuda grass (*Echinochloa colona*) in rice (Singh and Singh, 2005). The maize-wheat system, covering over 1.83 million ha under zero-till with residue retention, is advocated for higher productivity (Shekhawat *et al.*, 2021). In Asia, cropping patterns are rapidly changing due to increased maize demand (Yakadri *et al.*, 2015). Maize is versatile crop, adapting well to various agro-climatic conditions, and accounts for about 9% of India’s national food security. It ranks third after rice and wheat as a crucial

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cereal crop (Dass *et al.*, 2018). The rising poultry and animal feed industries are driving higher maize grain demand (Shyam *et al.*, 2021; Singh *et al.*, 2018).

Maize productivity in India (2689 kg/ha) is significantly lower than the global average (5500 kg/ha), indicating a considerable gap (Singh *et al.*, 2018). Weeds are a major factor in this yield reduction, posing challenges in conservation agriculture (CA), especially with zero-till drills. This issue is acute in the Indo-Gangetic Plains (IGP) due to the scarcity of post-emergence herbicides. Available herbicides like atrazine, oxyfluorfen, 2,4-D, and pendimethalin mainly target broadleaf weeds, leaving grasses and sedges difficult to control, particularly under extreme soil moisture and labour shortages (Swetha *et al.*, 2015). Tillage modifications also affect weed seed dynamics, weed seeds are often concentrated in the topsoil of no till system (Mulugeta and Stoltenberg, 1997). Weed competition can reduce maize yields by up to 90% (Dalley *et al.*, 2006), with reported reductions ranging from 40% to 80% (Reddy and Tyagi, 2005). Herbicides are crucial for weed management in CA systems (Bhullar *et al.*, 2016). Traditional weed control involves manual weeding and spading, creating ridges and furrows 4-5 weeks post-seeding, demanding significant labour due to the slow initial growth and wide row spacing (60 cm).

Therefore, this research aimed to validate suitable tillage methods along with a sequential application of new generation herbicides such as tembotrione, which has a low application rate and operates through a different mode of action (HPPD inhibitor), or the use of cover crops to reduce weed growth. Additionally, the study aimed to highlight the benefits of zero tillage compared to conventional tillage practices.

MATERIALS AND METHODS

Location of experimental site, experimental design and environmental conditions: A field experiment was carried out during the rainy (*Kharif*) season of 2021–22 and 2022–23 at the ICAR-Indian Agricultural Research Institute (28°08'N latitude, 77°12' E longitude and at an elevation of 228.61 metres (750 feet) above mean sea level) New Delhi, India, in a split plot design (SPD) with 3 replications, comprising of 4 tillage methods in main plot and 5 weed-control treatments in sub-plot in maize. The research farm's semi-arid climate features dry, hot summers (May-June) with temperatures between 40° and 45°C, and cold winters (December-January) with lows around 2°C. Annual rainfall averages 650 mm, mostly between July and September. The yearly pan evaporation rate is about 850 mm. Wind speeds average 7.6 km/h in April and 3.5 km/h in October. During the rainy season, relative humidity ranges from over 90% to 45%.

Treatment Details: The treatments were comprised of four tillage methods *viz* conventional tillage maize (M1: CT-M), conventional tillage maize with green manure from preceding green gram (M2: CT-M+GM), zero tillage maize with residue retention at 3t/ha (M3: ZT-M+R), zero tillage maize with *Sesbania* co-culture as brown manuring/cover crop (M4: ZT-M+BM) in main plot and five weed control treatments, *viz* S1: Un-weeded check (UWC), S2: Pre (atrazine + pendimethalin @750g/ha, each) +1 Hand weeding (25 DAS), S3: Pre (atrazine + pendimethalin @750g/ha, each) + Post (tembotrione) @120g/ha, S4: Pre (atrazine + pendimethalin @750g/ha, each)+Post (Premix of mesotrione + atrazine) @120g/ha, S5: Weed free check in sub-plots were evaluated. Atrazine @ 750g/ha + pendimethalin @ 750g/ha as pre-emergence (day after sowing) and tembotrione @ 120 g/ha as post-emergence (30 DAS) were applied separately in the needed amount with 400 litres of water/ha by knapsack sprayer for sequential application of herbicides. A knapsack sprayer equipped with a flat-fan nozzle was used to apply @120g/ha of the ready-mix herbicide (Mesotrione 2.27%W/w + Atrazine 22.7%W/w) at 30 days after sowing (DAS).

Soil quality of experimental site: Soil of experimental site was sandy loam, with pH 7.5, low in organic C (0.32%), low in available N (148.4 kg/ha), high in P (30.8 kg/ha) and medium K (256.4 kg/ha). During the winter season (*Rabi*), wheat crop was cultivated with the stipulated treatments, and the leftover crop residues were applied in the subsequent rainy season (*kharif*) for maize cultivation. Following the wheat harvest, mung bean was cultivated as a green manure crop and then incorporated into the field as per the designated treatment.

Field Preparation and agronomic practice: The main plots were prepared in accordance with specific requirements, and within each main plot, five subplots were established to accommodate various methods of weed control, so the total plot number was 60 (4 main plot × 5 sub plot × 3 replication). In the conventional tillage (CT) plots, a tractor-drawn disc plough was used for ploughing, followed by levelling with a plunker. For zero tillage (ZT) plots with residues, the residue from the previous wheat crop was kept intact, while ZT plots without residues were left undisturbed. Additionally, a weed-free check was maintained, involving manual weeding carried out at intervals of 30, 60, and 90 days after sowing (DAS). On the same day as maize sowing, *Sesbania aculeata* L., a leguminous cover crop, was broadcasted at a rate of 15 kg/ha. This cover crop served the purpose of suppressing weeds during the early stages of maize growth and also acted as a source of brown manure. On the 30th day after sowing, the *Sesbania aculeata* was sprayed with 2,4-D herbicide at a rate of 0.25 kg/ha. After this treatment, the brown-

coloured residues of *Sesbania* were composted. Seeds of the 'PJM-1' hybrid maize, with a growth duration of 100-110 days, were sown using a 9-tine zero-till seed drill, maintaining a spacing of 60 cm between lines and a seed-to-seed interval of 20 cm. A calculated amount of nutrients, specifically 120-60-40 kg NPK/ha were applied on the basis of soil-test analysis in maize through urea, single superphosphate and muriate of potash, respectively.

Observations and statistical analysis: Weed species were counted from a 1m × 1m (1m²) quadrat, and density was given in number/m². The weeds were first dried in the sun, then placed in an electric oven set to 70°C until the weight remained constant. The dry weight was then calculated as g/m². For microbial biomass carbon (MBC) and fluorescein diacetate (FDA) analysis, moist soil samples were collected from each plot at a 0–15 cm depth in the flowering stages. The samples were kept moist and tested for microbial activity on the same day. The benefit-cost ratio for each treatment was calculated as the ratio of net returns to the cost of cultivation. The data on yield attributes were taken at harvest from 5 randomly chosen plants. The data were analysed using analysis of variance (ANOVA) for a split plot design to determine the significance of overall treatment differences using the “F” test and conclusion was drawn at 5% probability level. To assess weed control efficacy (WCE), weed control index (WCI), and weed index (WI), the following calculations were made according to Das (2008):

$$WCE (\%) = \frac{(\text{Weed density in Control plot} - \text{Weed density in treated plot})}{\text{Weed density in control plot}} \times 100$$

$$WCI (\%) = \frac{(\text{Weed dry matter in Control plot} - \text{Weed dry matter in treated plot})}{\text{Weed dry matter in control plot}} \times 100$$

$$WI (\%) = \frac{(\text{Crop yield in control plot} - \text{Crop yield in treated plot})}{\text{Crop yield in control plot}} \times 100$$

Two years data (2021-22 and 2022-23) were pooled before analysis. The standard error of the mean was calculated for each case. When the ‘F’ value from the ANOVA was significant, the least significant difference (LSD) was computed to test treatment significance. To address data variability, weed density and dry weight were normalized using the square-root [$\sqrt{(x+0.5)}$] transformation before ANOVA.

RESULTS AND DISCUSSION

Weed population and weed dry matter accumulation:

In the experimental plot, a diverse array of annual and perennial weeds were observed, encompassing both grassy weeds and broad-leaved weeds, as well as sedges. Among the narrow-leaved weeds, *Setaria viridis* L., *Digitaria sanguinalis* L., and *Dactyloctenium aegyptium* L. On the other hand, among the broad-leaved weeds, the dominant species were *Commelina benghalensis* L., *Amaranthus*

viridis L., *Trianthema portulacastrum* L., and *Digera arvensis* L. Additionally, among the perennial weeds, *Cyperus rotundas* L. and *Cynodon dactylon* L., were observed.

The study observed significant differences in total weed dry matter accumulation (g/m²) among treatments at 30, 60, and 90 days after sowing (DAS), detailed in Table 1. Initially, at 30 DAS, the effect of tillage was predominant in contrast, 60 and 90 DAS, the herbicide application became notably effective. At 30 DAS, CT-M had the highest weed dry weight, whereas ZT-M+BM exhibited the greatest reduction (10.4%). Similar trends were observed at 60 DAS, indicating effective weed control with herbicide application. Treatment S3 (Pre + Post application of tembotrione) showed the lowest weed dry weight at 60 DAS (9.8 g/m²), followed by hand weeding (S2) (24.5 g/m²) and Premix Meso+Atra application (S4) (25.8 g/m²), compared to the un-weeded check. These findings underscore the efficacy of S3 and ZT-Maize + *Sesbania* brown manure in reducing weed dry weight significantly at 60 DAS and 90 DAS.

However, the count of BLW was higher (80.7%) in conventional tillage (CT-M) plots compared to zero tillage (ZT) plots, and also the perennial weed species like sedges were more abundant in ZT plots than in CT plots (Figure:1). The grassy weed *Cynodon dactylon* was most prevalent in ZT-M+BM among the different establishing techniques, with 6.5 No./m² followed by ZT-M+R. *Amaranthus viridis* was the predominant broad-leaved weed, and CT-M had the highest number of it (3.3 No./m²), followed by CT-M+GM and ZT-M+R. *Cyperus rotundas* predominated among the sedges, particularly in ZT-M + R at 19.6 No./m² and ZT-M+BM and CT-M had the lowest count. The results demonstrate that *Sesbania* has a smothering effect as a cover crop, leading to a significant reduction in weed population at the experimental site. The S3 herbicide treatment, combining pre-emergence application of atrazine + pendimethalin (each @750g/ha) and post-emergence application of tembotrione (120g/ha) at 30

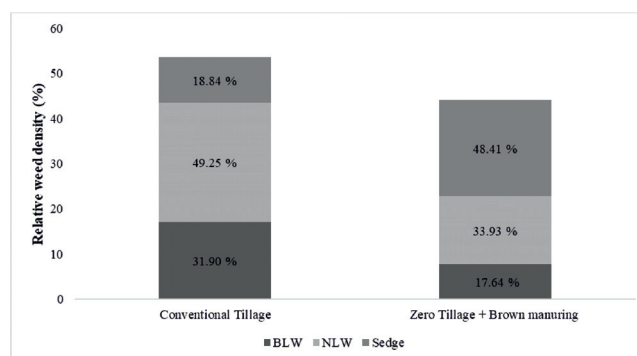


Fig. 1. Effect of crop establishment methods on weed distribution pattern in CT-M and ZT-M+BM plot

Where, BLW: Broad leaf weed; NLW: Narrow leaf weed;

Table 1. Effect of crop establishment methods and weed management on weed dry weight (g/m²) in maize (Two years pooled data)

| Treatment | 30 DAS | 60 DAS | 90 DAS |
|--|------------|-----------|-------------|
| <i>Crop establishment methods</i> | | | |
| CT-Maize | 7.7(71.2) | 4.6(26.2) | 7.7(72.7) |
| CT-Maize + Green manure | 7.4(65.4) | 4.4(23.9) | 7.5(68.2) |
| ZT-Maize + Residue* | 7.6(69.4) | 4.2(21.4) | 7.2(64.2) |
| ZT-Maize + <i>Sesbania</i> Brown manure | 7.3(63.8) | 3.8(18.4) | 6.9(59.3) |
| SEm± | 0.1(1.3) | 0.0(0.6) | 0.1(2.5) |
| CD (P=0.05) | 0.2(4.5) | 0.1(2.1) | 0.5(8.5) |
| <i>Weed management options</i> | | | |
| Un-weeded check | 10.0(99.3) | 7.2(52.3) | 11.4(129.2) |
| Pre +1 HW | 9.0(79.7) | 5.0(24.5) | 8.5(71.6) |
| Pre + Post (<i>Tembo</i>) | 8.8(76.7) | 3.2(9.8) | 7.8(61.0) |
| Pre + Post (Premix <i>Meso+Atra</i>) [§] | 9.1(81.6) | 5.1(25.8) | 8.3(69.0) |
| Weed free check | 0.7(0.0) | 0.7(0.0) | 0.7(0.0) |
| SEm± | 0.1(2.2) | 0.1(0.8) | 0.1(1.8) |
| CD (P=0.05) | 0.3(6.3) | 0.2(2.4) | 0.3(5.3) |

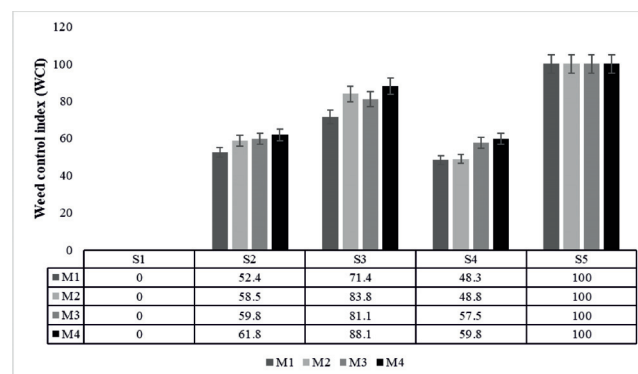
Note: CT, conventional tillage; ZT, zero tillage; * wheat residue @ 3t/ha; PRE, pre-emergence; POST, post-emergence; HW, hand weeding at 25 DAS; Tembo: tembotrione @ 120g/ha; §:pre-mix dose @ 120 g/ha. The data were subjected to square root transformation $\sqrt{x+0.5}$ before statistical analysis. Figures in parentheses are the original values.

DAS, significantly reduced weed density at 60 DAS for sedges (7.8/m²), narrow-leaf weeds (8.3/m²), broad-leaved weeds (3.9/m²), and total weeds (22.3/m²) as compared to the weed density of 30 DAS. In contrast, the un-weeded control (S1) had weed densities at 30 DAS of sedges (30.3/m²), grasses (31.9/m²), broad-leaved weeds (18.5/m²), and total weeds (80.8/m²), which increased further at 60 DAS (Table 2). This demonstrates that weed populations increased in the un-weeded control but decreased with the herbicide treatment, highlighting the effectiveness of tembotrione as a potent post-emergence herbicide.

The sequential application of atrazine @ 750 g/ha with pendimethalin @ 750 g/ha (pre)fb. tembotrione @ 120 g/ha (post) outperformed the other weed control techniques by considerably reducing the number of weed species (78.5% reduction over the weedy check) in comparison to S2 and S4. The decreased weed density (Table:2) and dry matter (Table:1) observed in these treatments could be attributed to the enhanced efficacy and extended impact of the applied HPPD-inhibiting herbicides. These herbicides not only curtailed weed growth but also led to a swift exhaustion of carbohydrate reserves in pre-germinated weeds. This depletion was facilitated by rapid respiration, leaf bleaching, reduced leaf area, and impaired photosynthesis. This finding is consistent with the studies conducted by Bollman *et al.*, (2008). According to Kumar *et al.* (2015), applying tembotrione (34.4% SC) post-emergence at a rate of 120 g/ha at 15 DAS resulted in a significant reduction in weed density and higher weed control efficiency.

Weed index (WI), Weed control index (WCI) and weed control efficiency (WCE): Weed index is a measure of

crop yield loss. Lower weed index values indicate successful suppression of weed growth and competition, resulting in reduced weed density and dry weight in experimental plots (Das 2008). Among treatments, S3:(Pre+Post application of Tembotrione) with M4: ZT-Maize + *Sesbania* brown manure (M4) yielded the best weed index values (7.04 and 8.37), indicating superior weed control and potential yield enhancement. The results show that the highest yield was obtained in the M4×S3 plot, which recorded a 69.35% increase in yield compared to the un-weeded control (UWC) (Figure:4). 60 DAS and 90 DAS, the weed control efficiency (WCE) (Figure:3) and weed control index (WCI) (Figure:2) were calculated to assess the effectiveness of weed management practices. At 30 DAS, the

**Fig. 2.** Effect of crop establishment methods and weed management on Weed control index (WCI) at 60 DAS

M1: CT-Maize; M2: CT-Maize + Green manure; M3: ZT-Maize + Residue*; M4: ZT-Maize + *Sesbania* Brown manure; S1: Un-weeded check; S2: Pre (atrazine + pendimethalin @ 750g/ha) +1 HW at 25 DAS; S3: Pre (atrazine + pendimethalin @ 750g/ha) + Post (tembotrione @ 120g/ha); S4: Pre (atrazine + pendimethalin @ 750g/ha) + Post (Premix mesotrione+atrazine @120g/ha) § ; S5: Weed free check.

Table 2. Effect of crop establishment methods and weed management option on weed density (No./m²) in maize (Two years pooled data)

| Treatment | 30 DAS | | | | 60 DAS | | | | 90 DAS | | | |
|-----------------------------------|-----------|-----------|-----------|-----------|-----------|-----------|-----------|-------------|------------|------------|------------|--------------|
| | BLW | NLW | Sedge | Total | BLW | NLW | Sedge | Total | BLW | NLW | Sedge | Total |
| <i>Crop establishment methods</i> | | | | | | | | | | | | |
| M ₁ | 3.5(17.1) | 4.7(26.4) | 2.8(10.1) | 3.8(57.6) | 3.0(11.4) | 4.5(21.3) | 2.8(9.5) | 6.3(49.7) | 2.92(9.7) | 5.34(33.6) | 3.58(16.1) | 6.98(59.5) |
| M ₂ | 3.2(11.3) | 4.8(27.1) | 3.1(12.0) | 2.6(50.4) | 2.8(9.4) | 4.0(19.5) | 2.8(9.3) | 5.7(41.7) | 2.76(8.3) | 5.40(34.9) | 3.51(14.9) | 6.91(58.2) |
| M ₃ | 3.0(9.8) | 4.6(24.8) | 4.5(25.1) | 2.5(59.8) | 2.6(7.7) | 3.7(17.4) | 3.7(19.6) | 5.4(38.3) | 2.45(6.5) | 5.42(35.2) | 3.61(16.7) | 6.90(58.5) |
| M ₄ | 2.7(7.8) | 4.1(15.0) | 4.3(21.4) | 2.4(44.2) | 2.4(6.5) | 3.4(15.0) | 3.6(16.1) | 5.3(35.6) | 2.13(5.0) | 5.12(31.6) | 3.70(16.3) | 6.60(53) |
| SEM± | 0.1(0.7) | 0.2(2.0) | 0.3(2.6) | 0.1(4.5) | 0.1(0.5) | 0.2(1.2) | 0.1(1.4) | 0.2(2.7) | 0.07(0.4) | 0.14(1.8) | 0.37(3.4) | 0.14(2.4) |
| CD (P=0.05) | 0.3(2.3) | NS | 0.9(9.1) | 0.3(15.5) | 0.4(1.9) | 0.7(6.6) | 0.5(4.8) | 0.7(9.5) | 0.25(1.4) | NS | NS | NS |
| <i>Weed management options</i> | | | | | | | | | | | | |
| S ₁ | 4.3(18.5) | 5.6(31.9) | 5.3(30.3) | 4.8(80.8) | 5.1(24.5) | 7.0(42.6) | 5.8(35.2) | 10.3(103.5) | 3.84(14.5) | 7.6(57.5) | 5.92(35.2) | 10.36(107.2) |
| S ₂ | 3.3(10.8) | 5.6(31.3) | 4.2(19.3) | 2.6(61.5) | 2.8(7.4) | 4.4(19.9) | 3.6(13.3) | 6.3(39.8) | 2.83(7.8) | 6.16(37.9) | 3.88(15.7) | 7.82(61.4) |
| S ₃ | 3.6(13.0) | 5.1(26.3) | 4.0(17.7) | 2.0(56.9) | 2.1(3.9) | 2.8(8.0) | 2.7(7.8) | 4.7(22.3) | 2.47(5.8) | 5.80(33.9) | 3.58(13.8) | 7.33(53.6) |
| S ₄ | 3.4(11.5) | 5.7(33.4) | 4.1(18.4) | 2.8(63.3) | 2.9(7.9) | 4.6(21.1) | 3.4(11.9) | 6.4(40.8) | 2.99(8.7) | 6.34(40.1) | 3.90(15.5) | 8.03(64.2) |
| S ₅ | 0.7(0.0) | 0.7(0.0) | 0.7(0.0) | 0.7(0.0) | 0.7(0.0) | 0.7(0.0) | 0.7(0.0) | 0.7(0.0) | 0.71(0.0) | 0.71(0.0) | 0.71(0.0) | 0.71(0.0) |
| SEM± | 0.1(0.7) | 0.3(2.9) | 0.3(2.7) | 0.1(4.5) | 0.1(0.7) | 0.2(2.3) | 0.2(1.9) | 0.2(3.3) | 0.12(0.8) | 0.19(2.4) | 0.22(1.9) | 0.19(3.1) |
| CD (P=0.05) | 0.3(2.2) | 0.7(8.4) | 1.0(7.7) | 0.4(13.0) | 0.4(2.0) | 0.7(6.6) | 0.7(5.4) | 0.7(9.6) | 0.35(2.1) | 0.55(6.8) | 0.64(5.6) | 0.56(8.8) |

M₁, CT, Maize; M₂, CT, Maize + Green manure; M₃, ZT, Maize + Sesbania Brown manure; M₄, ZT, Maize + Sesbania Brown manure; S₁, Un-weeded check; S₂, Pre (atrazine + pendimethaline @ 750 g/ha) + 1 HW at 25 DAS; S₃, Pre (atrazine + pendimethaline @ 750 g/ha) + Post (tembotrione @ 120 g/ha); S₄, Pre (atrazine + pendimethaline @ 750 g/ha) + post (Premix mesotrione + atrazine @ 120 g/ha); S₅, Weed free check

The data were subjected to square root transformation $\sqrt{x+0.5}$ before statistical analysis. Figures in parentheses are the original values.

establishment effects and weed management effects did not have a significant impact. At 60 DAS, the weed-free check plot had the highest weed control index value of 100%. The Pre+Post tembotrione treatment (S3) combined with ZT-Maize + *Sesbania* Brown manure (M4) was the second most effective, with a WCI of 88.1%. Weed management practices recorded better WCE which ranged from 56.5 % to 86.2% at 60 DAS, 41.2% to 58.2% at 90 DAS. At 60 DAS, weed-free check plot showed highest efficiency in controlling the weeds showing a value of 100%. The sequential application of atrazine @750 g/ha with pendimethalin at 750 g/ha (pre), fb Tembotrione @120 g/ha (post) (S3) along with ZT+BM (M4) showed the second-best efficiency in terms of weed control efficiency by showing a value of 86.2%, followed by in the application of same herbicide in ZT+R plot which showed a value of 83.1%.

This might be due to higher efficacy of herbicides which resulted in lower weed density, weed dry weight along with the smothering effect of cover crop *Sesbania*. Similar reports of higher WCE with tank mix of HPPD inhibiting herbicides with atrazine have been given by Jonathon *et al.* (2013), Madhavi *et al.* (2014). At 90 DAS, the trends in WCE values remained consistent, the effect could be attributed to the pre-emergence application of pendimethalin or atrazine, which suppressed the initial surge of weeds. This suppression was further complemented by the subsequent post-emergence application of tembotrione, which potentially managed the subsequent wave of weeds. As a result, this combined approach led to enhanced weed control across all the different tillage practices. These findings suggest that alongside the application of pre-emergence herbicides (atrazine or pendimethalin), the inclusion of tembotrione at a rate of 120 g/ha could potentially enhance the efficiency of weed control for the crops.

Maize yield attribute and yield: The yield and yield attributes of maize crop differed significantly due to tillage and weed-control measures. The highest grain yield of maize was achieved with ZT-M+BM (M4) applied plot (6.72 t/ha), 17.7% increase in grain yield compared to CT-M (5.53 t/ha). Additionally, the weed-free check plot exhibited a 25.43% increase in grain yield compared to the un-weedy check plot., which remained notably higher than other weed manage-

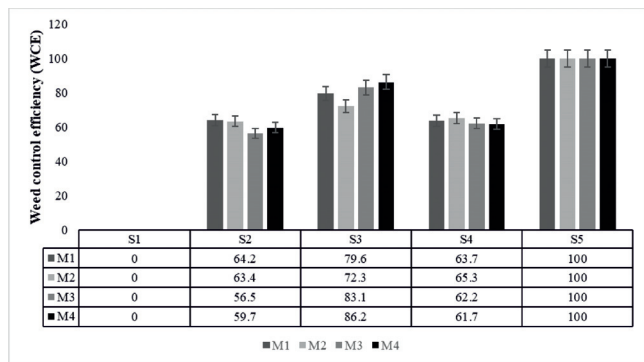


Fig. 3. Effect of crop establishment methods and weed management on Weed control efficiency (WCE) at 60 DAS

M1: CT -Maize; M2: CT-Maize + Green manure; M3: ZT-Maize + Residue*; M4: ZT-Maize + Sesbania Brown manure; S1: Un-weeded check ; S2: Pre (atrazine +pendimethaline @ 750g/ha) +1 HW at 25 DAS; S3: Pre (atrazine +pendimethaline @ 750g/ha) + Post (tembotrione @120g/ha); S4: Pre (atrazine +pendimethaline @ 750g/ha) + Post (Premix mesotrione+atrazine @120g/ha) § ; S5: Weed free check.

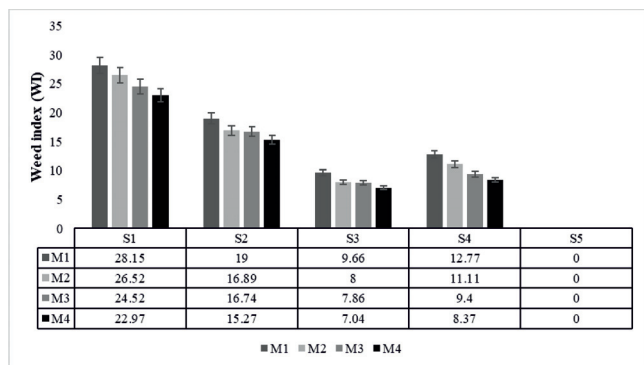


Fig. 4. Effect of crop establishment methods and weed management on Weed index (WI)

M1: CT -Maize; M2: CT-Maize + Green manure; M3: ZT-Maize + Residue*; M4: ZT-Maize + Sesbania Brown manure; S1: Un-weeded check ; S2: Pre (atrazine +pendimethaline @ 750g/ha) +1 HW at 25 DAS; S3: Pre (atrazine +pendimethaline @ 750g/ha) + Post (tembotrione @120g/ha); S4: Pre (atrazine +pendimethaline @ 750g/ha) + Post (Premix mesotrione+atrazine @120g/ha) § ; S5: Weed free check.

ment methods (Figure:5). ZT-M+BM (M4) demonstrated higher values for cobs length, cob girth, cob weight, shelling percentage, number of grains per cob, and 100 grain weight. On the other hand, the M1: CT-M plot showed the lowest values for these yield attributes (Table:3). The ZT-maize with *Sesbania* brown manuring also exhibited the highest total biological yield, surpassing CT-maize. Additionally, the ZT+BM treatment yielded the higher straw yield. The weed-free treatment (WFC) resulted in significantly higher values for cob length, cob girth, cob weight, shelling percentage, number of kernel rows per cob, number of kernels per row, and 100-grain weight at harvest (Table:3). These results were comparable to the Pre + Post (Tembotrione) and Pre + Post (Premix Meso+Atra) treatments. The treatment receiving sequential application of atrazine @ 750 g/ha with pendimethalin @ 750 g/ha (pre)

fb. tembotrione at 120 g/ha as post-emergence recorded significantly higher grain yields (6.32 t/ha) after WFC (Figure:5).

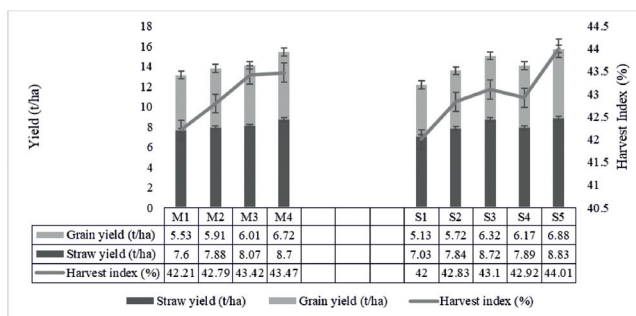


Fig. 5. Effect of crop establishment methods and weed management on total biomass, grain yield, total straw yield and harvest index

M1: CT-Maize; M2: CT-Maize + Green manure; M3: ZT-Maize + Residue*; M4: ZT-Maize + Sesbania Brown manure; S1: Un-weeded check; S2: Pre (atrazine +pendimethaline @ 750g/ha) +1 HW at 25 DAS; S3: Pre (atrazine +pendimethaline @ 750g/ha) + Post (tembotrione @120g/ha); S4: Pre (atrazine +pendimethaline @ 750g/ha) + Post (Premix mesotrione+atrazine @120g/ha) § ; S5: Weed free check.

Gupta *et al.* (2018) observed that the highest stover yield in hybrid maize was attained through a pre-emergence treatment involving a combination of atrazine 50 WP and pendimethalin 30 EC, each applied @ 750 g/ha, within 24 hours of sowing. With the pre-emergence application of atrazine 50 WP @ 1.0 kg/ha after 24 hours of sowing, it was followed by a sequential post-emergence application of tembotrione 34.4 SC @120 g/ha on 25 DAS. The stover yield obtained under this treatment remained at par with two hand weeding done on 20 and 40 DAS. Similarly, Sharma *et al.* (2018) revealed that significantly higher grain and stover yields for maize were recorded under no tillage conditions, surpassing outcomes from conventional tillage methods.

Among the weed management methods, S5 (weed-free check) achieved the highest net returns at 112,320/ha followed by S3 (Pre + Post Tembotrione) at 109,230/ha, and S2 (Pre + 1 HW at 30 DAS) at 97,730/ha. In contrast, W1 (un-weeded check) yielded net returns of 77,530/ha. Although the weedy check had the lowest cultivation costs, it resulted in the lowest returns due to reduced yields. In terms of net returns, ZT-Maize + Sesbania Brown manure (M4) performed the best, with a value of 116,570/ha, followed by CT-Maize with 94,320/ha. Among the crop establishment methods, ZT-maize with Sesbania brown manuring (M4) achieved the highest net benefit-cost (B:C) ratio of 3.71, surpassing other methods. For weed management, the Pre+Post (Tembotrione) (S3) option had the highest net B:C ratio of 3.01, outperforming other options (Table:3). The superior B:C ratios for ZT-maize with Sesbania brown manuring and Pre+Post (Tembotrione)

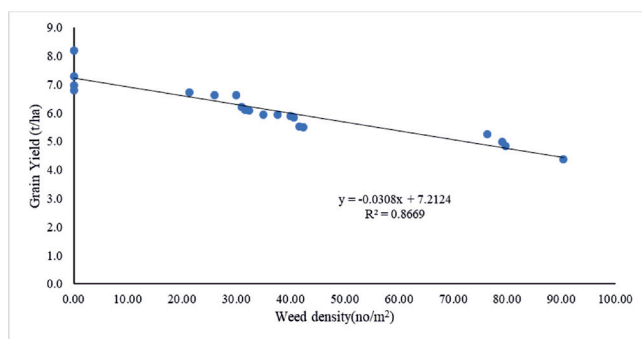
Table 3. Effect of crop establishment methods and weed management on cob length (cm), cob girth (cm), cob weight (g), shelling %, kernel no/cob, Kernel row/cob, Kernel weight/cob, Seed index and economics of maize at harvest (Two years pooled data).

| Treatment | Cob length (cm) | Cob girth (cm) | Cob weight (g) | Shelling % | Karnel row/cob | Kernel No./row | Kernel weight/cob (g) | Seed index (g) | B:C ratio |
|--|-----------------|----------------|----------------|------------|----------------|----------------|-----------------------|----------------|-----------|
| <i>Crop establishment methods</i> | | | | | | | | | |
| CT-Maize | 13.3 | 12.7 | 117.7 | 72.0 | 11.7 | 27.0 | 83.8 | 22.8 | 2.70 |
| CT-Maize + Green manure | 13.4 | 12.9 | 119.5 | 73.6 | 12.3 | 27.0 | 86.8 | 23.0 | 2.26 |
| ZT-Maize + Residue* | 14.6 | 13.7 | 123.9 | 76.0 | 12.5 | 28.8 | 88.0 | 23.8 | 2.38 |
| ZT-Maize + <i>Sesbania</i> BM | 16.1 | 15.8 | 130.1 | 81.6 | 13.4 | 29.9 | 98.5 | 24.5 | 3.71 |
| SEm± | 0.4 | 0.4 | 2.5 | 1.9 | 0.2 | 0.6 | 2.0 | 0.4 | - |
| CD (P=0.05) | 1.4 | 1.2 | 8.6 | 6.5 | 0.5 | 2.1 | 7.1 | 1.2 | - |
| <i>Weed management options</i> | | | | | | | | | |
| Un-weeded check | 11.5 | 12.0 | 110.3 | 69.2 | 10.9 | 25.9 | 75.8 | 22.0 | 2.43 |
| Pre +1 HW | 13.7 | 13.1 | 119.2 | 71.6 | 11.7 | 26.4 | 81.8 | 21.8 | 2.70 |
| Pre + Post (<i>Tembotrione</i>) | 15.4 | 14.6 | 126.5 | 80.6 | 13.2 | 29.4 | 96.9 | 24.2 | 3.01 |
| Pre + Post (Premix <i>Meso+Atra</i>) [§] | 14.8 | 13.9 | 122.5 | 70.1 | 12.5 | 27.9 | 82.3 | 23.2 | 2.73 |
| Weed free check | 16.5 | 15.4 | 135.6 | 87.3 | 14.1 | 31.9 | 109.5 | 26.4 | 2.65 |
| SEm± | 0.4 | 0.4 | 3.6 | 2.2 | 0.3 | 0.8 | 2.1 | 0.5 | - |
| CD (P=0.05) | 1.1 | 1.3 | 10.5 | 6.3 | 0.7 | 2.2 | 6.1 | 1.5 | - |

Note: CT, conventional tillage; ZT, zero tillage; *wheat residue @ 3t/ha; PRE, pre-emergence (atrazine + pendimethaline @ 750 g/ha each); POST, post-emergence; HW, hand weeding at 25 DAS; Tembo, tembotrione @ 120 g/ha; §:pre-mix dose, mesotrione + atrazine @ 120 g/ha. BM: Brown manuring (*Sesbania*)

were due to their higher yields and lower cultivation costs.

Correlation coefficient analysis between weed density (no/m²) and grain yield (t/ha) in maize: The graph showing the correlation between the weed density (no/m²) and grain yield (t/ha) of maize at 60 DAS. A negative linear correlation between weed density and yield in maize crop suggests that as the density of weeds increases, the yield of maize decreases in a linear manner. This suggests that increasing the number of weeds has a detrimental impact on the growth and productivity of maize, because weeds compete with the maize crop for essential resources such as water, nutrients, and sunlight. As weed density increases, they consume a larger share of these resources, leaving fewer available for the maize plants. This competition can lead to reduced growth, lower photosynthesis rates, and ultimately, a decrease in the yield of maize. We found the R² value 0.86 (Figure:6). It clearly suggested that weed

**Fig. 6.** Correlation between weed density (no/m²) and grain yield (t/ha) of maize

biomass accounted for 86% variation in grain yield. The outcome is backed by the research conducted by Mitra *et al.* in 2018.

Microbial biomass carbon and fluorescein diacetate hydrolysis activity: Microbial biomass carbon (MBC) and fluorescein diacetate (FDA) serve as indicators of microbial activity, and these parameters showed significant variations based on different crop establishment methods and weed management options. At the flowering stage of maize, MBC was highest under M4: ZT-maize with *Sesbania* co-culture as brown manure (156.01 µg/g soil), surpassing all other treatments. Similarly, FDA at the flowering stage of maize was also notably higher under (M4): ZT-maize with *Sesbania* co-culture as brown manure (133.78 µg/g soil) compared to other establishment methods. Among the different weed management options, MBC at the flowering stage was highest in the weed-free check (148.65 µg/g soil), outperforming the other treatments. For maize, FDA at the flowering stage was also higher in the (S3) Pre+ Post (*Tembotrione*) plot (116.27 µg/g soil), although not statistically significant compared to the unweeded check (Figure:7).

The increased microbial activity in the ZT-maize treatment, both with brown manure and residue retention, likely contributed to the higher MBC in the soil. Overall, the combination of organic matter accumulation, reduced soil disturbance, moisture conservation, carbon sequestration, and nutrient retention in ZT systems provides an advantageous environment for soil microorganisms, resulting in higher microbial biomass carbon compared to conventional

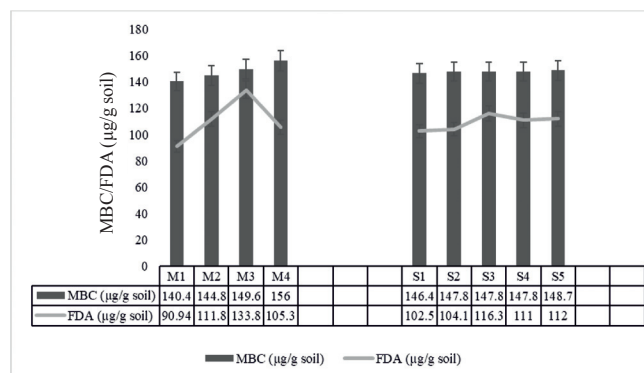


Fig. 7. Effect of crop establishment methods and weed management on microbial biomass carbon (MBC) and fluorescein diacetate hydrolysis activity (FDA) at flowering in maize. M1: CT-Maize; M2: CT-Maize + Green manure; M3: ZT-Maize + Residue*; M4: ZT-Maize + *Sesbania* Brown manure; S1: Un-weeded check; S2: Pre (atrazine + pendimethaline @ 750g/ha) +1 HW at 25 DAS; S3: Pre (atrazine + pendimethaline @ 750g/ha) + Post (*tembotrione* @120g/ha); S4: Pre (atrazine + pendimethaline @ 750g/ha) + Post (Premix *mesotrione* + *atrazine* @120g/ha)§ ; S5: Weed free check.

tillage practices (Sturz and Christie, 2003). Zero tillage involves minimal soil disturbance compared to conventional tillage (CT) methods. This preservation of soil structure and the undisturbed environment create favourable conditions for soil microorganisms to thrive. The reduced disturbance allows the microbes to establish and multiply, leading to higher FDA activity. In ZT systems, crop residues are left on the soil surface, providing a continuous source of organic matter. The presence of these residues enhances microbial activity, as they serve as a readily available food source for soil microorganisms. More organic matter leads to higher microbial activity, which is reflected in the increased FDA levels. Moreover, root nodulation in *Sesbania* brown manure leads to increased rhizodeposition/bioturbation, creating a tilled layer within the soil depths, which could explain the larger microbial population in the brown manure (Roldan *et al.*, 2003).

Thus, for effective weed control and achieving high maize productivity ZT with brown manure, alongside the sequential application of atrazine @ 750g/ha with pendimethalin @ 750 g/ha (pre-emergence), and tembotrione (34.4 EC) @ 120 g/ha may be recommended in the Indo-Gangetic plains of India.

REFERENCE

Bhullar, M.S., Pandey, M., Kumar, S. and Gill, G. 2016. Weed management in conservation agriculture in India. *Indian Journal of Weed Science* **48**(1): 1–12.

Bollman, J.D., Boerboom, C. M., Becker, R. L. and Fritz, V. A. 2008. Efficacy and tolerance to HPPD-inhibiting herbicides in sweet corn. *Weed Technology* **22**(4): 666–674.

Dalley, C.D., Bernards, M.L and Kells, J.J. 2006. Effect of weed removal timing and row spacing on soil moisture in corn (*Zea mays* L.). *Weed Technology* **20**: 399–409.

Das, T.K. 2008. Weed science: basics and applications. Jain brothers.

Dass, S., Jat, S.L., Chikkappa, G.K. and Parihar, C.M. 2018. Crop production management to climate change. *Food Security and Climate Change*, 251–287.

Giller, K. E., Andersson, J. A., Corbeels, M., Kirkegaard, J., Mortensen, D., Erenstein, O. and Vanlauwe, B. 2015. Beyond conservation agriculture. *Frontiers in plant science* **6**: 870.

Gupta, S.K., Mishra, G.C. and Purushottam. 2018. Efficacy of pre and post emergence herbicide on weed control in *kharif* maize (*Zea mays* L.). *International Journal of Chemical Studies* **6**(1): 1,126–1,129.

Jonathon R, Kohrt and Christy L and Sprague. 2013. Weed height and the inclusion of atrazine influence control of multiple resistant Palmer amaranth with HPPD inhibitors. *Weed Technology* **43**(2): 534–545.

Kumar, J.K., Anil Kumar, A.K., Vikas Sharma, V.S., Rajeev Bharat, R.B. and Singh, A.P. 2015. Bioefficacy of post-emergence tembotrione application on weed dynamics and productivity of maize in rainfed foothill and mid-hill conditions.

Madhavi, M., Ramprakash, T., Srinivas, A. and Yakadri, M. 2014, February). Topramezone (33.6% SC)+ Atrazine (50%) WP tank mix efficacy on maize. In Biennial Conference of Indian Society of Weed Science on “Emerging Challenges in Weed Management (p. 23).

Mitra, B., Bhattacharya, P. M., Ghosh, A., Patra, K., Chowdhury, A. K. and Gathala, M. K. 2018. Herbicide options for effective weed management in zero-till maize. *Indian Journal of Weed Science* **50**(2): 137–141.

Mulugeta, D. and Stoltenberg, D.E. 1997. Weed and seedbank management with integrated methods as influenced by tillage. *Weed Science* **45**: 706–15.

Reddy, D.A. and Tyagi, S.K. 2005. Integrated weed management in maize groundnut cropping system, *Agricultural Reviews*. **26**: 235–248

Roldán, A., Caravaca, F., Hernández, M.T., Garcya, C., Sánchez-Brito, C., Velásquez, M. and Tiscareno, M. 2003. No-tillage, crop residue additions, and legume cover cropping effects on soil quality characteristics under maize in Patzcuaro watershed (Mexico). *Soil and Tillage Research* **72**(1): 65–73.

Sharma, S., Marahattha, S., Sah, S.K and Karki, T.B., 2018. Efficacy of Different Tillage and Weed Management Practices on Phenology and Yield of Winter Maize (*Zea mays* L.) in Chitwan, Nepal. *International Journal of Plant & Soil Science* **26**(2): 1–11.

Shekhawat, K., Singh, V.K., Rathore, S.S., Rishi, Raj and Das, T.K. 2021. Achieving Sustainability in Food Systems: Addressing Changing Climate through Real Time Nitrogen and Weed Management in a Conservation Agriculture-Based Maize–Wheat System. *Sustainability* **13**(9): 5010.

Shyam, C.S., Rathore, S.S., Kapila, S., Singh, R.K., Padhan, S.R. and Singh, V.K. 2021. Precision nutrient management in maize (*Zea mays*) for higher productivity and profitability. *Indian Journal of Agricultural Sciences* **91**(6): 933–935.

Singh, G. and Singh, V.P. 2005. Compatibility of clodinafop-propargyl and fenoxaprop-p-ethyl with carfentrazone-ethyl, metsulfuron-methyl and 2, 4-D. *Indian Journal of Weed Science* **37**(1 and 2): 1–5.

Singh, M.V., Kumar, N. and Srivastava, R.K. 2018. Effect of

- nutrient management on maize (*Zea mays*) hybrid in eastern zone of Uttar Pradesh. *Annals of Plant and Soil Research* **20**(1): 99–102.
- Soni, J.K., V.K. Choudhary, P.K. Singh and S. Hota 2020. Weed management in conservation agriculture, its issues and adoption: a review. 9–19.
- Sturz, A.V. and Christie, B.R. 2003. Beneficial microbial allelopathies in the root zone: the management of soil quality and plant disease with rhizobacteria. *Soil and Tillage Research* **72**(2): 107–123.
- Swetha, K., Madhavi, M., Pratibha, G. and Ramprakash, T. 2015. Weed management with new generation herbicides in maize. *Indian Journal of Weed Science* **47**(4): 432–433.
- Yakadri M., Leela Rani P., Ram Prakash T., Madhavi M. and Mahesh N. 2015. Weed management in zero tillage maize. *Indian Journal of Weed Science* **47**(3): 240–245.



Effects of nitrogen supply on defensive changes in maize against biotic stressors

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ABSTRACT

The maize yield potential is constrained by a diverse range of biotic and abiotic factors, ultimately leading to diminished crop yield, and quality. Nitrogen (N)-an indispensable fertilizer element is known to exert an influence on incidence and severity of these biotic stresses. This paper describes the effect of various levels of N application and contrasting maize genotypes on weed infestation, maydis leaf blight (MLB) and fall armyworm (FAW) incidence in maize. The field experiment was carried out at ICAR-Indian Agricultural Research Institute, New Delhi during two consecutive years (2021 and 2022). Treatments comprising 6 maize genotypes (PJHM 1, PC 4, DKC 9167, PMH 13, AH 4271 and Pusa Vivek QPM 9-I) and seven N levels (0, 40, 80, 120, 160, 200 and 240 kg N/ha) were arranged in a factorial randomized complete block design. Results showed that genotypes with profuse growth, greater leaf area and higher light interception (PJHM 1, DKC 9167 and PMH 13) had minimum weed incidence and may be considered as a key element of integrated weed management in smallholder agriculture. Disease severity in PV QPM 9-I (5.3) was higher than all other genotypes while least in AH 4271 (2.7). The maximum and minimum pest incidence was observed in PJHM 1 (4.9 and 5.6,) and PV QPM 9-I (2.1 and 2.4), respectively. In general, the total (-9.4%) and broad-leaf weed density (-26.4%) reduced with increasing use of nitrogenous fertilizers, while the application of lower N rates reduced the prevalence of narrow-leaf weeds (34.2%). The early leaf senescence and poor photosynthetic rate at lower rates of N application decreased the plants immunity against MLB disease. Oppositely, the increased succulency at higher N doses led to severe FAW incidence in maize over control. Therefore, the study demonstrates that planting of competitive/resistant genotypes and use of 160 kg N/ha resulted in relatively less overall burden of biotic stressors on maize crop.

Key words: Corn, Fall armyworm, Maydis Leaf blight, Nitrogen, Plant health, Weed

Maize (*Zea mays* L.) an essential cereal and multipurpose species in the Poaceae family, is widely used for food, fuel, and industrial applications to make a number of products including maize starch, dextrose, syrup, and flakes (Singh *et al.*, 2022). Its biological plasticity allows to thrive well in a variety of climatic and soil conditions and, therefore, grown under diverse agro-ecologies untouched by other cereals. Maize is the only cereal crop gifted with the highest yield potential, and genetic diversity. It is becoming a popular crop in India due to its potential use in ethanol production. It is India's third-largest basic food crop in terms of output and acreage, after rice and wheat. Maize is grown on 9.86 million hectares area in India, contributing 31.5 million tonnes produce (DES, 2021). How-

ever, the prevalence of various biotic stresses like disease, insect-pest and weeds has become a potential yield limiting factor in many maize growing regions across the country. Among various biotic constraint, interference from weeds is a major threat to maize productivity. Maize is quite vulnerable to weed competition mainly at early crop growth stages. In maize crop, the potential yield losses due to weeds can range from 51 to 100%, in the absence of effective weed control strategies (Ghosh *et al.*, 2020). Of the 61 main diseases affecting maize, maydis leaf blight (MLB) is the most important foliar disease in most of the maize growing belts in the world. This massive foliar disease is caused by ascomyceteous fungus *Cochliobolus heterostrophus* (Drechs.), a necrotrophic plant pathogen that kills leaf tissues and may result in 70% yield losses in susceptible genotypes of maize (Manjunatha *et al.*, 2019). Fall army worm (FAW), *Spodoptera frugiperda* (J. E. Smit) has emerged as the most devastating pest of maize in the recent years (Sharanabasappa *et al.*, 2018). Under severe infection, this voracious pest may cause up to 100%

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yield loss in corn, if control measures are adopted (Sharanabasappa *et al.*, 2018).

Nitrogen stands as a prominent nutrient that significantly influences plant metabolism, development, and physiology (Kumar *et al.*, 2022). It is intricately linked to fundamental plant processes, such as photosynthesis, amino acid synthesis, and the tricarboxylic acid cycle. It is crucial nutrient for maize since it improves the vegetative growth, leaf area, leaf production, chlorophyll content, photosynthesis, yield and overall quality (Bamboriya *et al.*, 2023). The dose and source of N influence the diversity, density and proliferation and community structure of crop-associated weeds (Ghosh *et al.*, 2020). Sub-optimal application of N may favor certain weed species and therefore, increase the herbicide demand (Jha *et al.*, 2017). The N alters plants ability to respond to biotic stressor, including attacks from herbivores as it can induce changes in host plant is morphology, biochemistry, physiology and microclimate (Aydogdu and Boyraz, 2011). In general, N poses a negative effect on plant's physical defence mechanism and secretion of anti-pathogen phytoalexins and also regulates the plant ability to bounce back from biotic stresses. Nitrogen is also known to affect the plants nutrition and therefore, nutritional supply to herbivores. Hence, a field study was conducted to study the impact of N fertilizer on plant biotic stresses in diverse genotypes of maize crop. We hypothesize that optimizing N dose for different genotypes will significantly improve the crop resistance against biotic stresses in maize.

MATERIALS AND METHODS

Field experiments were conducted over two consecutive years (2021 and 2022) at ICAR-Indian Agriculture Research Institute, New Delhi, India (28° 38'23" N and 77° 09'27" E). The experimental site is situated a in semi-arid and subtropical climate, with extremes of both cold and heat. The minimum and maximum temperature during the

kharif season was 17.0 and 38.2°C during 2021 and 18.6 and 38.8° C during 2022, respectively. The total rainfall received during the *kharif* season of 2021 and 2022 was 1256 and 821 mm, respectively. The mean relative humidity (RH) was 78.1% and 74.2% during 2021 and 2022, respectively. Soil of the experimental site was sandy loam in texture, low in organic C (0.44 %) and available N (185 kg/ha) content, medium in available phosphorus (12.8 kg P/ha) and available potassium (205 kg K/ha), non-saline (0.65 dS/m EC) and slightly alkaline in chemical reaction (7.7 pH).

The factorial experiment was laid-out in a randomized complete block design (RCBD) and replicated twice. The treatments consisted of six genotypes of maize (PJHM 1, PC 4, DKC 9164, PMH 13, APH 4271 and PV QPM 9-I) and seven N levels (0, 40, 80, 120, 160, 200 and 240 kg N/ha). Genotypes with contrasting nature (differing in maturity, yield potential and N response) were chosen for the experimental purpose (Table 1). Maize genotypes were planted on 15th and 9th July during 2021 and 2022, respectively. The seeds were sown at 5 cm depth following row-to-row spacing of 60 cm and plant-to-plant spacing of 20 cm. In order to protect the crop from seed and soil borne diseases, seeds were treated with carbendazim 50 WP @ 3 g/kg seed. Recommended dose of P (80 kg P₂O₅/ha) and K (60 kg K₂O/ha) were applied before planting of the crops through single-superphosphate and muriate of potash, respectively. The N was applied through urea in three equal splits at sowing, 30 and 45 DAS. For weed control, atrazine @ 750 g/ha was used as pre-emergence herbicide. Two to three irrigations were applied to maize as per crop need. The FAW (*Spodoptera frugiperda*) was controlled by repeated spray of emamectin benzoate @ 200 g/ha.

The leaf area index (LAI) for each treatment was measured using leaf area meter (Model LICOR 3000, USA). The SS1 SunScan plant canopy analyzer was used to quantify photosynthetically active radiation (PAR) interception

Table 1. Characteristics of the maize genotypes

| Genotype | Type | Maturity group | Yield potential | N responsiveness |
|------------|---------------------------------|-----------------------------------|--------------------------------|--|
| PJHM 1 | Dual purpose hybrid | Medium-maturity (90-95 days) | High yielding (6.5 t/ha) | Extremely receptive to fertilizer N and can show positive N response up to 200 kg N/ha |
| PC 4 | Composite variety | Early maturity (89-90) days | Low yield potential (4.5 t/ha) | Performs better under low input and moisture stress conditions |
| DKC 9164 | Hybrid | Late maturity (105-110 days) | High yielding (6.5 t/ha) | - |
| PMH 13 | Hybrid | Medium maturity (97 days) | High yielding (5.9 t/ha) | - |
| APH 4271 | Advanced hybrid | Medium maturity (90-95 days) | High yielding (6.4 t/ha) | - |
| PV QPM 9-I | Pro-vitamin-A rich maize hybrid | Extra early maturity (75-80 days) | Yield potential (5.5 t/ha) | - |

at silking. The measurement of the chlorophyll and carotenoid content was done by acetone method. The photosynthetic rate was measured at silking stage using Infrared Gas Analyzer (LI6400). A 0.25 m² quadrat was randomly placed between the central rows of each plot to measure the weed density and species composition of the weeds at 50 DAS. Weed species were recognized and counted and the data were subjected to square root transformation $\{\sqrt{(x+0.5)}\}$. The MLB diseases severity was visually estimated using for rating scale. The scale consisted of 9 categories designated by numerals 1 to 9. Scale 1 represents nil infection, 2 indicates light infection, 3–4 represents slight infection, 5 indicates moderate infection, 6–7 represents heavy infection and 8–9 indicates very heavy infection. Ten randomly selected plants/plot were evaluated for MLB and degree of infection was assigned to each plant. The average of the ten plants was computed and expressed between 1 to 9. The Davis scale was used to estimate the FAW damage on the maize leaves. Ten plants/plot were randomly chosen at knee-high stage and 0–9 score was assigned to each plant. Zero score indicates no harm, 1–4 represents moderate damage, 5–7 represents medium damage, and 8–9 represents significant damage. By averaging all of the ten sampled plants, the average damage score per plot was calculated.

Data were statistically analysed using the “Analysis of Variance Technique” with SAS 9.3 software. Least significant difference (LSD) values at the 5% level of probability were used to compare the treatments.

RESULTS AND DISCUSSIONS

Growth and physiological parameters

The growth and physiological parameters of plant depend on the type of genotype. The LAI and photosynthetic radiation interception were maximum in PHM 13, DKC 9164 and PJHM 1 (Table 2). The genotypic difference in PAR interception might be caused by potential variations in genotype's leaf area and leaf orientation. Chlorophyll content and photosynthetic rate were substantially higher in PJHM 1, PMH 13 and AH 4271. PV QPM 9-I registered the lowest value of these growth and physiological parameters. Significant genotype variability in chlorophyll content, and PAR interception were also reported earlier by Chikoye *et al.* (2008).

The data revealed that when N levels increased from 0 to 240 kg N/ha, the LAI, intercepted PAR, chlorophyll content and photosynthetic rate consistently increased. The lowest total values of all these parameters were found in control with no N. The reduced LAI and intercepted PAR at unfertilized plots might be owing to the hampered leaves production and reduced leaf size as a result of poor plant growth under severe N stress. The primary cause of low chlorophyll values and photosynthetic rate in the absence of N is the breakdown of proteins and plastids, which slows down or stops chlorophyll synthesis (Choudhary and Behra, 2020).

Weed dynamics

During the maize cropping season, the major weeds

Table 2. Plant growth and physiological parameters of maize as affected by genotype and N levels at silking stage during 2021 and 2022

| Treatment | LAI | | Intercepted PAR (%) | | Chlorophyll content (mg/g of fresh leaf) | | Photosynthetic rate ($\mu\text{mole CO}_2/\text{m}^2/\text{sec}$) | |
|-----------------------------------|------|------|---------------------|------|--|------|---|------|
| | 2021 | 2022 | 2021 | 2022 | 2021 | 2022 | 2021 | 2022 |
| <i>Genotype (G)</i> | | | | | | | | |
| 'PJHM 1' | 3.79 | 3.85 | 59.8 | 61.6 | 1.12 | 1.03 | 32.6 | 33.7 |
| 'PC 4' | 3.77 | 3.83 | 52.6 | 55.4 | 1.02 | 0.96 | 27.1 | 27.3 |
| 'DKC 9164' | 3.83 | 3.94 | 60.3 | 62.3 | 1.06 | 1.02 | 29.2 | 30.4 |
| 'PMH 13' | 3.85 | 3.96 | 61.6 | 62.6 | 1.07 | 1.04 | 30.0 | 29.8 |
| 'AH 4271' | 3.73 | 3.79 | 58.3 | 61.3 | 1.10 | 1.02 | 31.3 | 32.2 |
| 'PV QPM 9-I' | 2.84 | 2.94 | 46.5 | 47.3 | 0.98 | 0.94 | 23.5 | 25.2 |
| CD (P=0.05) | 0.24 | 0.13 | 1.8 | 2.9 | 0.06 | 0.07 | 1.7 | 1.8 |
| <i>Nitrogen level (N) (kg/ha)</i> | | | | | | | | |
| 0 | 2.51 | 2.58 | 44.4 | 48.3 | 0.70 | 0.55 | 22.8 | 24.2 |
| 40 | 3.06 | 3.14 | 51.1 | 53.7 | 0.86 | 0.73 | 24.4 | 26.2 |
| 80 | 3.44 | 3.52 | 55.0 | 57.4 | 0.97 | 0.89 | 27.3 | 28.1 |
| 120 | 3.89 | 3.97 | 56.8 | 59.1 | 1.13 | 1.09 | 29.8 | 30.0 |
| 160 | 4.02 | 4.09 | 61.1 | 61.0 | 1.19 | 1.17 | 31.3 | 32.2 |
| 200 | 4.19 | 4.26 | 63.1 | 63.6 | 1.27 | 1.27 | 32.8 | 33.5 |
| 240 | 4.34 | 4.41 | 64.3 | 65.8 | 1.32 | 1.32 | 34.1 | 34.3 |
| CD (P=0.05) | 0.26 | 0.14 | 1.9 | 3.1 | 0.06 | 0.07 | 1.9 | 1.9 |
| Interaction (G×N) | NS | * | * | * | * | NS | * | * |

LAI- leaf area index; PAR- photosynthetically active radiation

were *Cyperus rotundus*, *Phyllanthus niruri*, *Convolvulus arvensis*, *Dactyloctenium aegyptium*, *Digitaria sanguinalis*, *Amaranthus viridis* and *Eragrostis tenella*. The structure of the genotype canopy has been observed to influence the weed density. Among the genotypes, the grassy weed density was in the order of PV QPM 9-I > AH 4271 = PMH 13 = DKC 9164 = PJHM 1 > PC 4 while a different trend was observed for broad-leaf weeds (PC 4 > PV QPM 9-I > AH 4271 > PMH 13 > DKC 9164 > PJHM 1). Sedges counts did not differ significantly among the genotypes (Table 3). Total weed density was 9.7–12.1 % lower with genotypes having higher LAI and intercepted PAR (PJHM 1, DKC 9164 and PMH 13) (Table 3), indicating that these genotypes were more competitive than weeds and may be a key element of integrated weed management in smallholder agriculture. The short stature and poor vegetative growth of PV QPM 9-I led to maximum weed density (8.56 and 9.16 weeds/m²). The LAI serves as a valuable tool in forecasting crop losses caused by weeds and is crucial for understanding crop-weed competition dynamics. Earlier Jha *et al.* (2017) also reported that a crop having a denser canopy (high LAI) can diminish weed competitiveness by limiting the amount of light available for weed growth and development. The correlation analysis also showed that LAI ($r=-0.59$) and intercepted PAR ($r=-0.73$) of maize was negatively related with total weed density.

The rates of N applications significantly affected the grassy, broad-leaf and total weed density over control. Population density of grassy weeds (53.4%) was positively related with N levels. Moreover, grassy weeds are more

competitive for applied N due to their greater N absorption efficiency, hence, they preferred N fertilized environment. In contrast, N application had negative effect on broad-leaf weeds as their higher count (up to 35.9 %) was observed in control plot as compared to 240 kg N/ha. Sedges density increased with N application up to 200 kg N/ha and declined thereafter. Total weed count was significantly reduced (-9.4%) with N fertilization over control mainly due to enhanced leaf area and greater PAR absorption at higher N levels.

MLB disease severity

The MLB was the only corn disease seen in the experimental plots. Disease development and severity of MLB was highly dependent on prevailing weather conditions. The incidence of MLB was observed during first year only when higher atmospheric humidity (>75%) and moderate temperature (17 to 38.2 °C) favoured sporulation, and lesion expansion (Manjunatha *et al.*, 2019). During the second year of the study, weather conditions (RH < 75 and low temperature) were not favourable for the disease incidence to appear.

Disease resistance frequently differs among plant species, as various genotypes showcased distinct patterns of chemical and physical defensive mechanisms. Among the tested varieties, 'PV QPM 9-I' was found most susceptible to MLB disease with the highest MLB disease scale (5.3) (Fig. 1). Conversely, 'AH 4271' displayed the lowest MLB disease scale (2.7), signifying that this particular genotype curtailed pathogen multiplication, thereby showcasing

Table 3. Weed density as affected by genotypes and N levels in maize during 2021 and 2022.

| Treatment | Weed density (Number/m ²) at 50 DAS | | | | | | | |
|-----------------------------------|---|------|--------|------|-------------------|------|-------------|------|
| | Grassy weeds | | Sedges | | Broad- leaf weeds | | Total weeds | |
| | 2021 | 2022 | 2021 | 2022 | 2021 | 2022 | 2021 | 2022 |
| <i>Genotype (G)</i> | | | | | | | | |
| 'PJHM 1' | 4.78 | 5.13 | 2.25 | 2.64 | 5.09 | 5.90 | 7.53 | 8.26 |
| 'PC 4' | 4.57 | 5.03 | 1.83 | 2.22 | 6.91 | 7.17 | 8.45 | 9.06 |
| 'DKC 9164' | 4.82 | 4.81 | 2.17 | 2.56 | 5.39 | 5.85 | 7.56 | 8.03 |
| 'PMH 13' | 4.77 | 5.15 | 2.10 | 2.51 | 5.81 | 5.90 | 7.53 | 8.24 |
| 'AH 4271' | 4.82 | 5.19 | 2.15 | 2.53 | 6.69 | 6.88 | 8.35 | 9.00 |
| 'PV QPM 9-I' | 5.26 | 5.58 | 1.98 | 2.37 | 6.84 | 6.87 | 8.56 | 9.16 |
| CD (P=0.05) | 0.3 | 0.25 | ns | ns | 0.3 | 0.24 | 0.22 | 0.26 |
| <i>Nitrogen level (N) (kg/ha)</i> | | | | | | | | |
| 0 | 3.62 | 3.86 | 2.37 | 2.92 | 7.06 | 7.66 | 8.48 | 9.03 |
| 40 | 4.30 | 4.52 | 2.50 | 2.83 | 6.72 | 7.15 | 8.39 | 8.88 |
| 80 | 4.46 | 4.98 | 2.33 | 2.68 | 6.46 | 6.82 | 8.15 | 8.84 |
| 120 | 5.05 | 5.36 | 2.09 | 2.57 | 6.28 | 6.24 | 7.94 | 8.58 |
| 160 | 5.34 | 5.64 | 1.87 | 2.12 | 5.67 | 5.96 | 7.80 | 8.44 |
| 200 | 5.49 | 5.79 | 1.72 | 2.18 | 5.36 | 5.66 | 7.63 | 8.34 |
| 240 | 5.59 | 5.88 | 1.67 | 2.00 | 5.30 | 5.53 | 7.58 | 8.28 |
| CD (P=0.05) | 0.3 | 0.27 | 0.34 | 0.37 | 0.3 | 0.26 | 0.24 | 0.28 |
| Interaction (G×N) | * | NS | NS | NS | NS | * | * | NS |

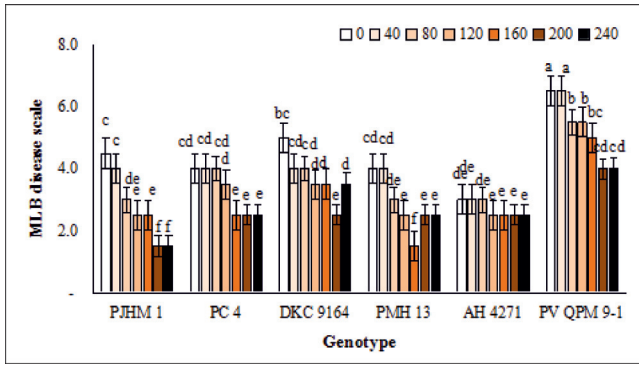


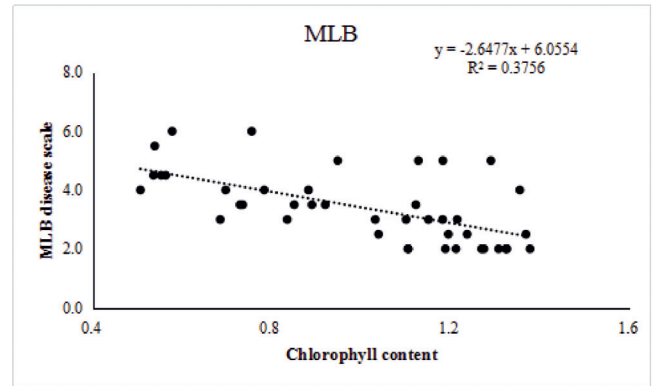
Fig. 1. Interaction effect of genotypes and N levels on MLB disease scale in maize during 2021. Error bars show standard error.

relative resistance to the disease. Manjunatha *et al.* (2019) reported that resistant maize genotypes had greater hairs on leaf and comparatively lesser stomatal openings over susceptible genotypes.

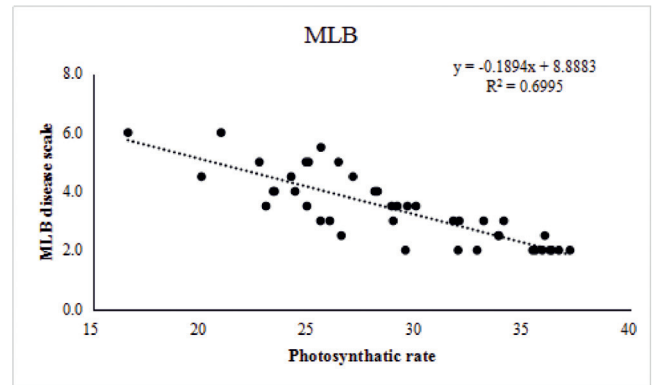
In addition to being a crucial nutrient for crop growth and yield, N has also been recognized to have a direct impact on the infection and severity of diseases (Aydogdu and Boyraz, 2011). The present study confirmed the positive effect of optimum N supply on maize defense mechanism against MLB, in which application of 160-200 kg N/ha resulted into least disease infection. The disease was more severe when N was not applied (4.2) or more than 160-200 kg N/ha was applied (3.2). Plants cultivated under N starved conditions, have poor defense mechanism against the pathogen (Aydogdu and Boyraz, 2011). We observed a negative correlation between leaf photosynthesis rate and chlorophyll content with MLB (Fig. 2). The *Cochliobolus heterostrophus* (Drechs.) is an necrophytic/semi saprophytes facultative parasite that prefers senescing leaf or produce harmful chemicals to destroy leaf tissue. Hence, the reduced chlorophyll and increased rate of senescence at N starved condition increased the disease susceptibility with low N application. Contrarily, the improved metabolic activities like photosynthetic rate and chlorophyll production (Table 2) and reduced leaf senescence at high N levels might have increased the resistance towards the facultative parasite (Manjunatha *et al.*, 2019). On the other hand, N abundance might have increased plant succulence and reduced the cell wall thickness which make the plant more susceptible to pathogens (Aydogdu and Boyraz, 2011).

Pest incidence

The FAW is a major pest that feeds on maize crop. Significant effect of genotypes and N levels was observed on FAW infestation (Fig. 3). The average FAW damage score was 3.5 to 4.0 during 2021 and 2022, respectively. Geno-



(a)



(b)

Fig. 2. Correlation between MLB disease scale and chlorophyll content (a) and photosynthetic rate (b) in maize during 2021.

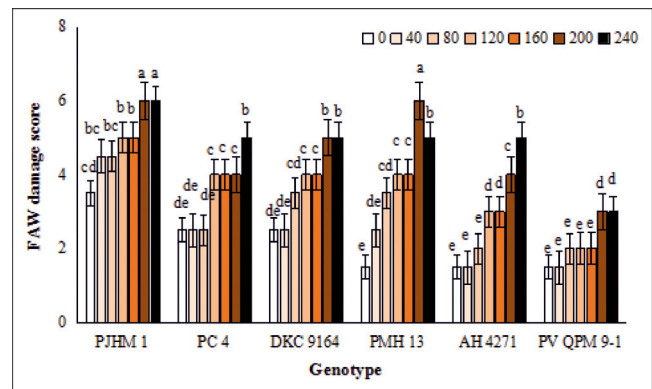


Fig. 3. Interaction effect of genotypes and N levels on FAW incidence in maize (mean of two years). Error bars show standard error (P=0.05).

type PJHM 1 had the highest FAW damage score (4.9 and 5.6) while, PV QPM 9-I had the lowest damage score (2.1 and 2.4). The observed resistance of maize genotypes to FAW could be due to increased defense protein, greater amino acid and glucose content, and jasmonic acid accumulation (Wang *et al.*, 2022). Leaf physical characteristics like leaf toughness and cuticle structure might have been the reason for increased resistance of PV

QPM 9-I against FAW.

The plant's ability to defend against pests is significantly influenced by environmental factors, including N fertilization (Wang *et al.*, 2022). Increased rates of N application from 0 kg to 200 kg N/ha increased the FAW damage in maize and the damage score remained relatively constant at 200–240 kg N/ha. The lowest level of N fertilization (0 kg/ha) reduced FAW damage by 50% as compared to the highest level (240 kg N/ha). Ample N availability in maize led to a significant rise in leaf area, N and protein content which improved leaf quality. As a result, leaf-chewing *S. exigua* larvae displayed a preference for feeding on high-N maize. Earlier, Wang *et al.* (2022) also found that excess N application increases soluble amino acids, soluble protein and soluble sugar consequently, attracted FAW larvae to feed on maize leaves.

Weeds, diseases and pests jointly stand as a key yield limiting factor for maize. Genotypes AH 4271, PJHM 1 and PMH 13 showed relatively higher resistance to MLB, while PV QPM 9-I had slight tolerance to the FAW, should be promoted. Crop grown without N or with sub-optimal doses of N were more vulnerable to severe weed infestation as well as leaf blight attack. Oppositely, over application of N led to heavy infestation of fall army worm. Therefore, cultivation of competitive/resistant varieties using optimal N application could be a cost-effective and eco-friendly approach for biotic stress management in maize.

REFERENCES

- Aydogdu, M. and Boyraz, N. 2011. Effects of nitrogen and organic fertilization on corn smut (*Ustilago maydis* (DC) Corda.). *African Journal of Agricultural Research* **6**(19): 4,539–4,543.
- Bamboriya, S.D., Dhar, S., Upadhyay, P.K., Dass, A., Meena, R.P. and Garg, K. 2023. Evaluation of maize (*Zea mays*) genotypes under different nitrogen levels in a Trans-Gangetic Plains region. *Indian Journal of Agronomy* **68**(4): 368–372.
- Chikoye, D., Lum, A.F., Abaidoo, R., Menkir, A., Kamara, A., Ekeleme, F. and Sanginga, N. 2008. Response of corn genotypes to weed interference and nitrogen in Nigeria. *Weed Science* **56**(3): 424–433.
- Choudhary, R.L. and Behera, U.K. 2020. Effect of conservation agriculture and nitrogen management on root architecture and soil properties in maize–wheat cropping system. *Journal of Soil and Water Conservation* **19**(3): 261–270.
- Department of Economics and Statistics (DES). 2021. Agricultural Statistics at a Glance.
- Ghosh, D., Brahmachari, K., Brestic, M., Ondrisik, P., Hossain, A., Skalicky, M., Sarkar, S., Moulick, D., Dinda, N.K. and Das, A. 2020. Integrated weed and nutrient management improve yield, nutrient uptake and economics of maize in the rice-maize cropping system of Eastern India. *Agronomy* **10**: 1906. <https://doi.org/10.3390/agronomy10121906>.
- Jha, P., Kumar, V., Godara, R. and Chauhan, B. 2017. Weed management using crop competition in the United States: A review. *Crop Protection* **95**: 31–37.
- Kumar, V., Dhyani, B.P., Shahi, U.P., Kumar, S., Kumar, A. and Singh, A., 2022. Effect of nitrogen schedule and management on yield of late-sown wheat (*Triticum aestivum*) in rice–wheat system. *Indian Journal of Agronomy* **67**(2): 144–147. <https://doi.org/10.59797/ija.v67i2.104>
- Manjunatha, C., Gogoi, R., Singh, B., Jeevan, B., Rai, S.N. and Singh, P.K. 2019. Phenotypic and physiological characterization of maize inbred lines resistant and susceptible to maydis leaf blight. *Indian Phytopathology*. <https://doi.org/10.1007/s42360-019-00117-w>
- Sharanabasappa, S.D., Kallelshwaraswamy, C.M., Asokan, R., Swamy, H.M.M., Maruthi, M.S. and Pavithra, HB. 2018. First report of the fall armyworm, *Spodoptera frugiperda* (JE Smith) (Lepidoptera: Noctuidae), an alien invasive pest on maize in India. *Pest Management in Horticulture Ecosystems* **24**(1): 23–29.
- Singh, B., Mundra, S.L. and Kaushik, M.K. 2022. Effect of nutrient management and plant density on productivity of QPM hybrids of maize (*Zea mays*). *Indian Journal of Agronomy* **67**(1): 26–29. <https://doi.org/10.59797/ija.v67i1.80>
- Wang, W., Wang, X., Liao, H., Feng, Y., Guo, Y., Shu, Y. and Wang, J. 2022. Effects of nitrogen supply on induced defense in maize (*Zea mays*) against fall armyworm (*Spodoptera frugiperda*). *International Journal of Molecular Sciences* **23**(18): 10,457.

Poplar based agroforestry system: Symmetry to maximize productivity and optimized nutrient acquisition in fodder sorghum–wheat rotation in semiarid region of Haryana

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ABSTRACT

A field experiment was conducted during the *kharif* and *rabi* season of 2 years (2022–24) at the farm of agroforestry of Chaudhary Charan Singh Haryana Agricultural University, Hisar to evaluate the impact of different geometry of poplar on the yield and nutrient uptake of sorghum and wheat under poplar-based agroforestry systems. The experiment was laid out in a randomized block design with 3 replications. The sorghum and wheat were sown as per the treatment comprising different spacing of poplar i.e. 3 m × 3 m, 4 m × 3 m, 5 m × 3 m, 6 m × 3 m, 7 m × 3 m, 8 m × 3 m and control (sole crops without trees). The results showed that sorghum (14.02 and 14.48 t/ha) dry fodder yield and wheat grain yield (5.14 and 5.30 t/ha) and straw yield (7.17 and 7.28 t/ha) were maximum under control in 2022–23 and 2023–24, respectively. The yield of sorghum (13.62 and 15.54%), wheat grain (44.55 and 45.66%) and wheat straw (39.05 and 39.15%) were lower at 3 m × 3 m spacing compared to control in 2022–23 and 2023–24, respectively. The increase in spacing of poplar increase the yield of sorghum and wheat during both the years of study i.e. least yields at 3 m × 3 m popular spacing and highest under 8 m × 3 m spacing. However, popular based system yields of sorghum (8.01 and 8.42%), wheat grain (50.18 and 50.00%) and wheat straw (42.56 and 42.44%) were higher under 8 m × 3 m than 3 m × 3 m spacing in 2022–23 and 2023–24, respectively. Similar significant results were obtained in case of nutrient uptake N, P and K as yield of sorghum (143.9, 147.2, 18.3, 19.9 and 31.4, 29.2 kg/ha) and wheat in grain (81.8, 83.4, 13.7, 14.3 and 13.3 14.4 kg/ha) and straw (26.8, 28.4, 7.5, 8.7 and 64.2, 66.3 kg/ha) under 8 m × 3 m during 2022–23 and 2023–24, respectively. Hence, control has significant effect on the yield and nutrient uptake of crops than under agroforestry systems. While, among all the treatments of poplar-based alley crop systems, spacing of 8 × 3 m the significantly higher green forage, and grain yields and nutrient uptake.

Key words: Nutrient content, Nutrient uptake, poplar spacing, Yield

The challenge of ensuring food security and achieving higher productivity from limited natural resources has led to the overexploitation and injudicious use of chemical fertilizers. This misuse has resulted in further land degradation, environmental problems, and low productivity in the semi-arid tropics of India (Gupta, 2019). Despite India being one of the leading countries in terms of animal population, with 536 million units, milk productivity remains remarkably low. One major reason for this low milk pro-

ductivity is the limited availability of green fodder for livestock. The country faces an estimated 35 percent deficit in green and dry fodder due to decrease in the area under forage crops over the past 3–4 decades, as farmers have preferred cereal crops and other cash crops. This deficiency in forage availability makes livestock rearing more challenging (Sirohi *et al.*, 2022). The situation becomes critical during the dry season under rain-fed conditions when no crops can typically be grown and natural pastures, grasses, and weeds become unproductive. Farmers resort to feeding their animals with low-quality hay made from stored crop residues or travel long distances to gather green grasses or fodder (Mallikarjun *et al.*, 2018). Agroforestry systems (AFS) incorporate diverse methods of using trees and crops for the management of land, and show considerable benefits for the efficient use of agricultural and forest resources (Qiao *et al.*, 2019). Tree-based agroforestry systems are far

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more economically feasible and environmentally friendly than mono-cropping systems. Agroforestry systems provide benefits such as improved water quality, biodiversity, reduced soil erosion, increased aesthetic value, carbon sequestration, and mitigation of climate change (Gurmessa *et al.*, 2021). Agroforestry is regarded as a cure the ills of intensive agriculture. It prevents land degradation and increases site production through interactions among trees, soil, and crops, restoring soil fertility. Effective agroforestry systems rely heavily on tree spacing and shape (Rizvi *et al.*, 2020). Poplar is India's most effective industrial agroforestry tree species, with annual yield ranging from 10 to 30 m³/hectare. A poplar-based agroforestry unit is a huge success in irrigated parts of northern India. This approach is practical and more economically successful than several other harvest rotations in India (Sirohi and Bangarwa, 2017). Selecting suitable forage and cereal crops that can be integrated with poplar crucial for enhancing feed supplies for livestock producers and economic yield for farmers. Sorghum (*Sorghum bicolor*) and wheat (*Triticum aestivum* L.) crop rotations can fulfill the fodder needs of livestock and productivity as well as address protein deficiency issues (Kumar *et al.*, 2012a, 2012b). However, further research is required to determine the best management practices for these crop rotations under poplar trees. To maintain intercrop productivity and maximize returns, adopting appropriate spacing for tree species is crucial in any agroforestry system since intensive agriculture methods have a worsening effect on soil fertility. Farmers can opt for agroforestry systems that not only replenish soil but also help to preserve crop output. The spacing between and within tree rows was a key factor influencing intercrop productivity (Handa *et al.*, 2019). Ensuring the ongoing intercrop productivity and optimizing returns necessitates adopting appropriate spacing for tree species in any agroforestry system. The arrangement between and within tree rows stands out as a critical factor influencing intercrop productivity (Chaturvedi *et al.*, 2016). Wider spacing between tree rows led to higher productivity of intercrops compared to narrow spacing. However, soil fertility increased more with narrow spacing, particularly close to the tree base rather than farther away. This study aimed to investigate the effect of poplar spacing on forage production and wheat productivity to identify suitable poplar-forage crop combinations in sorghum-wheat cropping system to enhance both fodder and grain yield.

MATERIALS AND METHODS

The field experiment was conducted during *kharif* and *Rabi* season of 2022–23 and 2023–24 at Research Farm of Forestry (29°10'N; 75°43'E), CCSHAU, Hisar. The experi-

ment was laid-out in a Randomized block design with 3 replications. The treatments consisted of 7 spacing of poplar transplanted in 2017. The poplar (clone G-3) was planted at different spacing of 3 m × 3 m, 4 m × 3 m, 5 m × 3 m, 6 m × 3 m, 7 m × 3 m, 8 m × 3 m and control (sole crop without tree). Sorghum-wheat rotation was taken under the different geometry of poplar. The gross plot size for each treatment varied based on the tree spacing and increased from 81 m² in 3 m × 3 m to 216 m² in 8 m × 3 m and spacing 5 m × 4 m was grown as control (devoid of trees) during their respective seasons. Sorghum 'HJ-541' was sown during first week of June, while wheat (DWB 187) was sown during first week of November in 2022–2023. Recommended dose of fertilizers were applied to the crops as per the recommendation of package and practice of CCSHAU. Similar, procedure was followed during 2023–24. Within each experimental unit, crop data were recorded from all spacings, randomly placed 1 m × 1 m quadrates. After being sun-dried for 4–5 days, the grains were accurately weighed and expressed as tonnes/hectare, as delineated by Rana *et al.* (2014).

Nutrient content and uptake: Nitrogen (N), phosphorus (P) potassium (K) and micronutrients (Fe, Cu, Zn and Mn) content were estimated by modified kjeldahl method (Prasad *et al.*, 2006), vanado-molybdo-phosphoric acid yellow color method (Jackson, 1973), flame photometer method (Jackson, 1973) and DTPA extractable (Lindsey and Norvell, 1978) respectively. Nutrient uptake was calculated by multiplying nutrient content with fodder and wheat yields.

$$\text{N uptake (kg/ha) in grain/straw} = [\% \text{ N in grain/straw} \times \text{grain/straw yield (kg/ha)}]$$

Analysis of variance was performed using the GLM procedures of the statistical analysis system (SAS Institute, Cary, NC) for randomized block design. The differences between treatment means were compared using a LSD test at $P < 0.05$ (Gomez and Gomez, 1984).

RESULTS AND DISCUSSION

Productivity of fodder sorghum and wheat

The results revealed that sorghum (14.02 and 14.48 t/ha) dry fodder yield and wheat grain (5.14 and 5.30 t/ha) and straw yield (7.17 and 7.28 t/ha) was significantly higher under the control (sole crops) than other poplar-based intercropping in 2022–23 and 2023–24, respectively in sorghum wheat cropping system (Table 1). The yield of both crops decreased with increased tree density. The sorghum dry fodder yield in sole crop was 8% higher than the yield at 3 m × 3 m spacing in 2022–23, and this difference increased to 8.4% in 2023–24. Similar results were obtained for wheat crop for both the years. The wheat grain and straw yields were higher under sole crop which was 33.3,

Table 1. Effect of different geometry of poplar on yield of sorghum and wheat under poplar based agroforestry system in 2022–23 and 2023–24

| Treatment | Sorghum dry fodder yield (t/ha) | | Wheat grain yield (t/ha) | | Wheat straw yield (t/ha) | |
|---------------------------|---------------------------------|------------|--------------------------|-----------|--------------------------|-----------|
| | 2022–23 | 2023–24 | 2022–23 | 2023–24 | 2022–23 | 2023–24 |
| <i>Poplar spacing (m)</i> | | | | | | |
| 3 × 3 | 12.11±0.39 | 12.23±0.45 | 2.85±0.52 | 2.88±0.53 | 4.37±0.43 | 4.43±0.45 |
| 4 × 3 | 12.15±2.68 | 12.27±2.71 | 3.33±1.16 | 3.35±1.18 | 5.01±0.80 | 5.08±0.81 |
| 5 × 3 | 12.39±3.00 | 12.51±3.04 | 3.59±1.35 | 3.61±1.37 | 5.36±0.93 | 5.43±0.95 |
| 6 × 3 | 12.53±3.10 | 12.66±3.15 | 3.76±1.44 | 3.77±1.45 | 5.54±0.99 | 5.61±1.01 |
| 7 × 3 | 12.92±3.04 | 13.08±3.09 | 4.12±1.45 | 4.25±1.46 | 6.03±1.01 | 6.11±1.03 |
| 8 × 3 | 13.08±2.80 | 13.26±2.86 | 4.28±1.36 | 4.32±1.37 | 6.23±0.95 | 6.31±0.97 |
| Control | 14.02±2.32 | 14.48±2.39 | 5.14±1.15 | 5.30±1.17 | 7.17±0.83 | 7.28±0.85 |
| CD (P=0.05) | 1.04 | 1.20 | 0.42 | 0.43 | 0.65 | 0.67 |

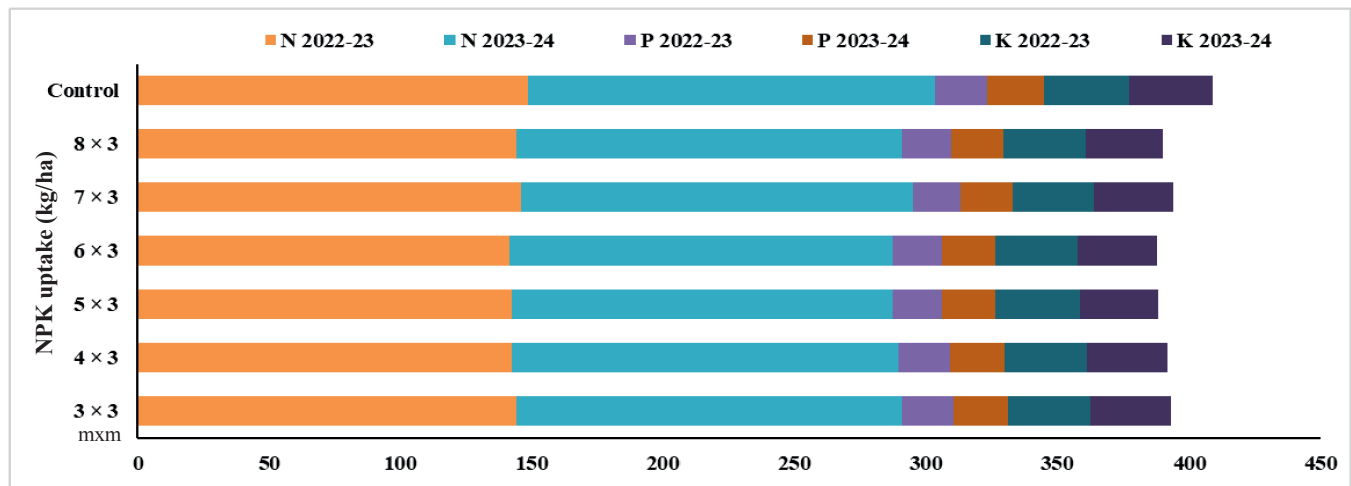
34.2% and 29.8, 29.9% than 3 m × 3 m in 2022–23 and 2023–24, respectively. This could be due to shade by the trees, which results in crops receiving reduced light intensity, restricting growth and decreasing agricultural output. Similar findings were corroborated by Sirohi *et al.* (2020) and Lamerre (2017), who showed higher intercrop yields with wider spacing compared to close spacing. Wider spacing leads to increased photosynthetic activity and crop development, resulting in higher productivity. Devi *et al.* (2020) and Meena *et al.* (2023) also detected a drop in light intensity in poplar-based agroforestry systems compared to solo cropping systems, resulting in a fall in intercrop yields.

Nutrient Acquisition

The nutrient uptake of sorghum was significantly affected, more nutrients were acquired under control than poplar based intercropping system (Figs. 1 and 2). The N, P, K, Fe, Cu, Zn and Mn uptake of sorghum was 3.12 and 5.53%, 1.30 and 4.43%, 1.30 and 4.43%, 2.41 and 4.15%, 8.47 and 10.89%, 10.26 and 12.24%, 13.03 and 15.59%, 11.70 and 13.77% higher in control than the

3 m × 3 m spacing of poplar in 2022–23 and 2023–24, respectively. Under poplar-based system, the highest uptake was observed in 8 m × 3 m spacing for macro and micro nutrients and then decreased with increased tree density during both years. The uptake of macro and micro nutrients increases from 2022–23 to 2023–24 in both poplar-based intercropping and solitary cropping. Similar findings were previously found by Sharma *et al.*, (2012), that the N, P, and K content and uptake by wheat crop decreased considerably under a poplar-based agroforestry system when compared to the control (without trees). They also discovered low quantities of N, P, and K, and their uptake in wheat plants, along the tree line and then increased with distance away from the tree line.

The nutrient uptake by wheat grain and straw was observed significantly higher under sole cropping (control) than poplar based agroforestry system (Figs. 3–4). The nutrient uptake by wheat grain for N, P, K, Fe, Cu, Zn and Mn ranged from 97.14–56.15 kg/ha, 13.70–10.26 kg/ha, 13.27–9.98 kg/ha, 206.78–120.64 g/ha, 36.03–22.23 g/ha, 129.11–82.34 g/ha and 127.37–73.47 g/ha in 2021. While

**Fig. 1.** Effect of plant spacing on poplar based agroforestry system on NPK uptake in fodder sorghum

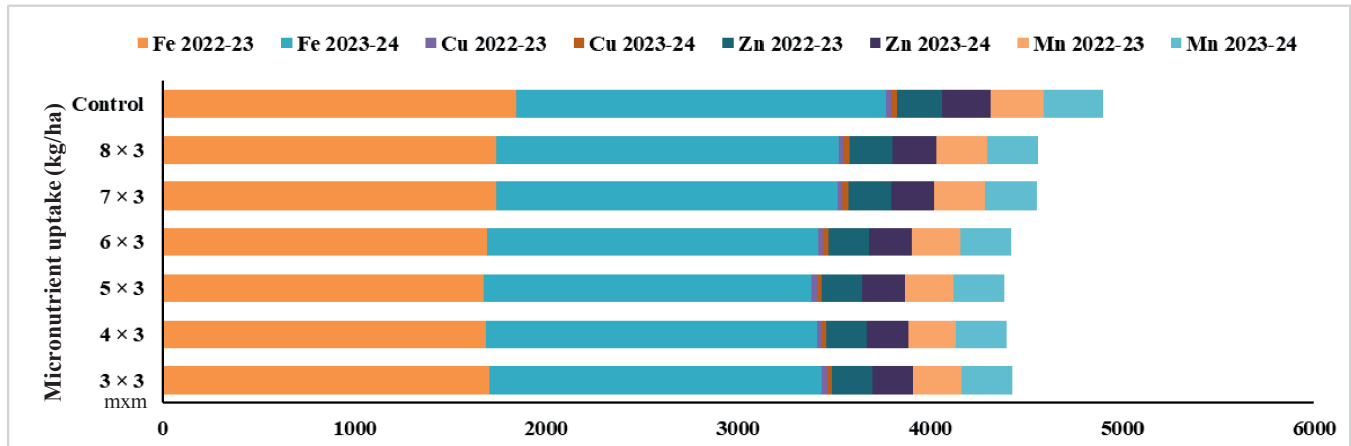


Fig. 2. Effect of plant spacing on poplar-based agroforestry system on Fe, Cu, Zn and Mn uptake in fodder sorghum

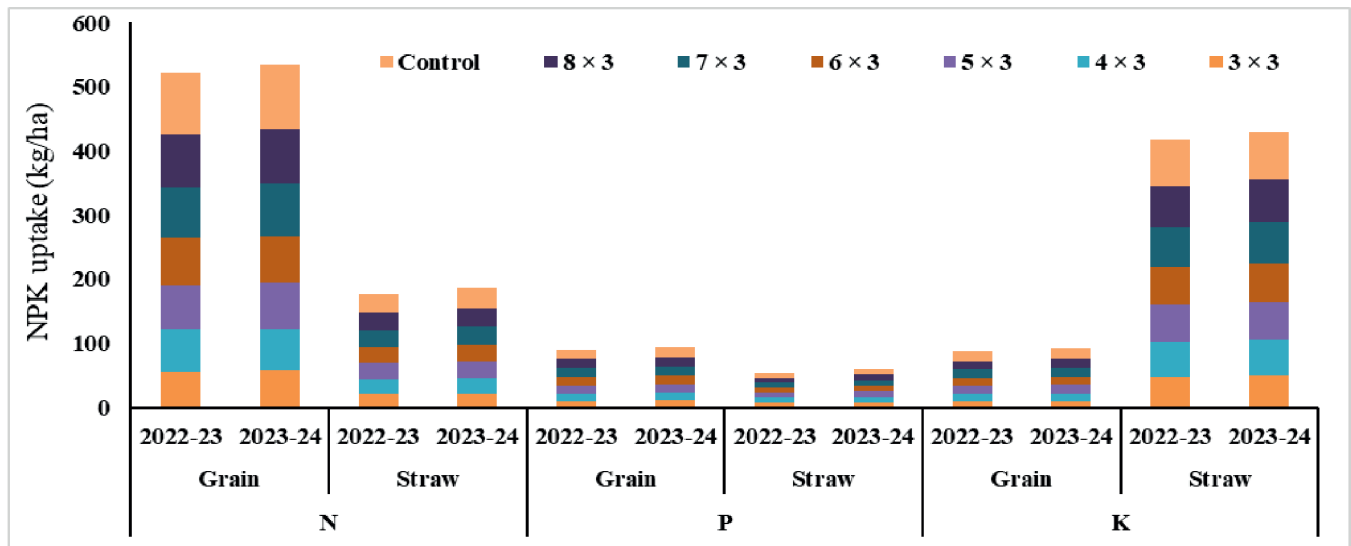


Fig. 3. Effect of plant spacing on poplar-based agroforestry system on NPK uptake by grain and straw in wheat

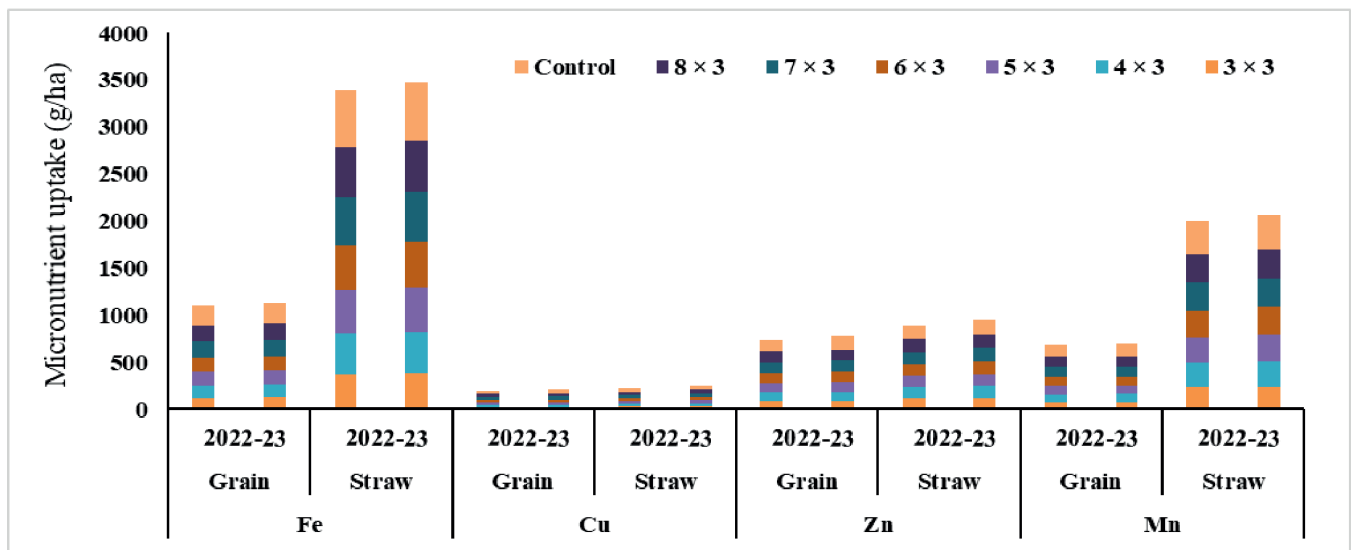


Fig. 4. Effect of plant spacing on poplar-based agroforestry system on Fe, Cu, Zn and Mn uptake by grain and straw in wheat

the nutrient uptake of wheat straw for N, P, K, Fe, Cu, Zn and Mn ranged from 29.40–20.98 kg/ha, 7.89–6.99 kg/ha, 72.42–48.07 kg/ha, 610.96–357.47 g/ha, 37.36–25.70 g/ha, 146.63–108.68 g/ha and 344.16–232.09 g/ha in 2021. The uptake of nutrients by wheat grain and straw increased from 2022–23 to 2023–24. Among the poplar-based system the highest nutrient uptake in wheat grain and straw was recorded at 8 m × 3 m spacing, which further decreased from 8 m × 3 m to 3 m × 3 m poplar spacing during both years of experiment. The wider geometries had higher uptake of macro and micro nutrients than the closer spacing of poplar trees during both years. Similar were the findings of Devi *et al.* (2020) and Meena *et al.* (2023).

Thus, study concluded that among the poplar-based agroforestry system widest tree spacing treatment (8 × 3 m) yielded the highest forage output of sorghum and grain and straw yield of wheat in two year of crop rotations. Uptake of macro-and micro-nutrient in sorghum–wheat rotation under the widest spacing (8 × 3 m) was the most productive compared to other tree spacing. Intercropping sorghum-wheat with poplar can help bridge the gap between the demand and supply of green forage and economic yield in semi-arid regions, promoting a more sustainable and productive land use system integrated with livestock.

REFERENCES

- Chaturvedi, O.P., Sikka, A.K., Handa, A.K. and Bajpai, C.K. 2016. Agroforestry Technologies for Different Agro-climatic zones of the Country. All India Coordinated Research project on Agroforestry, ICAR-Central Agroforestry Research Institute, Jhansi (UP).
- Christensen, B.T. 2001. Physical fractionation of soil and structural and functional complexity in organic matter turnover. *European Journal of Soil Science* **52**(3): 345–353.
- Devi, S., Bhardwaj, K.K., Dahiya, G. and Sharma, M.K. 2020. Assessment of yield and nutrient uptake of wheat in agri-silviculture system under semi-arid region of Haryana. *Indian Journal of Ecology* **47**(3): 866–868.
- Gomez, K.A. and Gomez, A.A. 1984. Statistical Procedures for Agricultural Research, 2nd edn, p 680. John Wiley and Sons, New York.
- Gupta, G.S. 2019. Land degradation and challenges of food security. *Review of European Studies* **11**(1): 63–63.
- Gurmessia, B., Ashworth, A.J., Yang, Y., Adhikari, K., Savin, M., Owens, P. and Corti, G. 2021. Soil bacterial diversity based on management and topography in a silvopastoral system. *Applied Soil Ecology* **163**, 103,918.
- Handa, A.K., Dev, I., Rizvi, R.H., Naresh, K., Ram, A., Dheeraj, K., Anil, K., Bhaskar, S., Dhyani, S.K. and Javed, R. 2019. Successful agroforestry models for different Agro-ecological regions in India. Published by ICAR-Central Agroforestry Research Institute, Jhansi and World Agroforestry Centre.
- Jackson, M.L. 1973. Soil chemical analysis. Printice hall of India Limited, New Delhi, p. 372.
- Kumar, S., Agrawal, R.K., Dixit, A.K., Rai, Arvind, K., Singh, J.B. and Rai, S.K. 2012a. Forage Production Technology for Arable Lands. *Indian Grassland and Fodder Research Institute*, Jhansi. Pp. 62.
- Kumar, S., Agrawal, R.K., Dixit, A.K., Rai, Arvind, K., Singh, J.B. and Rai, S.K. 2012b. Forage Production Technology for Arable Lands. *Indian Grassland and Fodder Research Institute*, Jhansi. Pp. 62.
- Lamerre, J., Schwarz, K.U., Langhof, M., von Wühlisch, G. and Greef, J.M. 2015. Productivity of poplar short rotation coppice in an alley-cropping agroforestry system. *Agroforestry Systems* **89**(5): 933–942.
- Lindsay, W.L. and Norvell, W. 1978. Development of a DTPA soil test for zinc, iron, manganese, and copper. *Soil science society of America journal* **42**(3): 421–428.
- Mallikarjun, R.H., Kumar, R., Meena, R.K. and Ginwal, D. 2018. Yield and chemical composition of cowpea (*Vigna unguiculata*) fodder as affected by tillage practices and nitrogen management. *Indian Journal of Animal Nutrition* **35**(3): 333–338.
- Meena, L.R., Meena, Samrath Lal, Kumar, Lalit, Pillai, Nataraja Subash and Ram, T., 2023. Evaluation of food and fodder based cropping systems for sustaining productivity, resource use efficiency and profitability in western plain zone of Uttar Pradesh. *Indian Journal of Agronomy* **68**(4): 398–403.
- Prasad, R., Shivay, Y.S., Kumar, D. and Sharma, S.N. 2006. Learning by doing exercise in soil fertility (A practical manual for soil fertility), Division of Agronomy, *Indian Agricultural Research Institute*, New Delhi, pp. 68
- Qiao, X., Sai, L., Chen, X., Xue, L. and Lei, J. 2019. Impact of fruit-tree shade intensity on the growth, yield, and quality of intercropped wheat. *PLoS One* **14**(4): e0203238.
- Rana, K.S., Choudhary, A.K., Sepat, S., Bana, R.S. and Dass, A. 2014. Methodological and analytical agronomy: Post Graduate School. IARI, New Delhi, p. 276.
- Rizvi, R.H., Handa, A.K., Sridhar, K.B., Singh, R.K., Dhyani, S.K., Rizvi, J. and Dongre, G. 2020. Spatial analysis of area and carbon stocks under *Populus deltoides* based agroforestry systems in Punjab and Haryana states of Indo-Gangetic Plains. *Agroforestry Systems* **94**(6): 2,185–2,197.
- Sharma, N.K., Singh, R.J. and Kumar, K. 2012. Dry matter accumulation and nutrient uptake by wheat (*Triticum aestivum* L.) under poplar (*Populus deltoides*) based agroforestry system. *International Scholarly Research Notices* (1): 359,673.
- Sirohi, C. and Bangarwa, K.S. 2017. Effect of different spacings of poplar-based agroforestry system on soil chemical properties and nutrient status in Haryana, India. *Current Science* **1,403–1,407**.
- Sirohi, C., Dhillon, R.S., Handa, A.K., Kumar, P., Bhardwaj, K.K., Kumari, S. and Chavan, S.B. 2020. Promising wheat cultivars for poplar (*Populus deltoides*) based agroforestry system in semi-arid ecosystem of Northern India. *Indian Journal of Agroforestry* **22**(1): 31–37.
- Yadav, R.S., Yadav, B.L., Chhipa, B.R. and Keshwa, G.L. 2005. Nutrient removal and yield of wheat (*Triticum aestivum* Linn.) as influenced by different tree species in agroforestry under semi-arid condition of Rajasthan. *Indian Journal of Agroforestry* **7**(1): 112–115.

Effect of pruning and grasses on forage productivity, carbon storage, soil health and economics of Anjan tree (*Hardwickia binata*) based silvopasture systems

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ABSTRACT

A field experiment was conducted during 2018 to 2023 on ten years old *Hardwickia binata* Roxb. based silvopasture system at Indian Grassland and Fodder Research Institute, Jhansi. The treatment consisted of three pruning intensities of *H. binata*, viz. 30%, 45% and 60% and establishment of three grasses, viz. *Cenchrus ciliaris*, *Chrysopogon fulvus* and *Panicum maximum* in association with *H. binata*. Pruning of branches of *H. binata* at 60% intensity recorded significantly higher top feed (TF 1.48, 1.77, 2.23, 2.68 and 3.27 t/ha) and fire wood yields (FW 2.74, 3.17, 3.49, 3.79 and 4.65 t/ha) as compared to 30% pruning intensity (TF 0.93, 1.01, 1.19, 1.55 and 2.08 t/ha and FW 1.76, 1.90, 1.98, 2.26 and 2.84 t/ha) and 45% pruning intensity (TF 1.21, 1.41, 1.75, 2.15 and 2.59 t/ha and FW 2.33, 2.59, 2.82, 3.08 and 3.63 t/ha) during 1st, 2nd, 3rd, 4th and 5th years of study, respectively. Among grasses, establishment of *C. fulvus* in association with *H. binata* recorded significantly higher dry pasture yields (7.91, 8.33, 8.66, 8.93 and 9.18 t/ha) as compared to *P. maximum* (6.19, 6.37, 6.54, 7.08 and 7.41 t/ha) and it was found at par with *C. ciliaris* (7.62, 8.15, 8.44, 8.70 and 8.86 t/ha) during 1st, 2nd, 3rd, 4th and 5th years of study. Establishment of *H. binata* based silvopasture systems on poor shallow soil and degraded land recorded 9.11-15.50% improvement in available nutrients (N : 12.73%, P : 15.50% and K : 9.11%) and organic carbon (OC 9.47%) in 5th year of experiment than initial year (N 229.39, P 8.32 and K 214.73 kg/ha and OC 0.584%). Similarly, *H. binata* recorded 111.31% higher carbon stock in 5th year of study (23.04 t/ha) as compared to initial year (10.90 t/ha). In term of monetary return, maximum net return and benefit-cost ratio was obtained from 60% pruning intensity (₹ 63459/ha and 2.08) followed by 45% pruning intensity (₹ 50263/ha and 1.91) from *H. binata* based silvopasture system.

Key words: Carbon storage, *Cenchrus ciliaris*, *Chrysopogon fulvus*, Forage productivity *Hardwickia binata*, *Panicum maximum*, Pruning intensities, Silvopasture systems

Establishment of silvopasture systems on degraded lands in hot arid and semiarid regions where erratic rainfall and recurrent drought is the common phenomenon can play an important role of bridging the gap in fodder supply during lean period of the year, enhancing fodder availability, boost carbon and nutrient in soil and checking soil erosion (Soni *et al.*, 2013; Sharma, 2014 and Verma *et al.*, 2023). In silvopasture systems grasses provide green forage during monsoon season and trees provide top feed during winter and summer seasons (Kumar *et al.*, 2017). In silvopasture systems, canopy management of tree components is essential to obtain a sustained yield of under-storey pasture, top feed and quality wood. Without proper prun-

ing management, trees develop greater taper and larger side branches which provide more shade to under-storey pasture and decrease their productivity and also taper development of trees and larger side branches produce larger knots on the stems and reduce the wood quality (Rosso and Ninin 1998). Canopy management in silvopasture systems also alleviate shade and facilitate penetration of light to under-storey pasture which improve the growth of pasture components than unpruned trees (Thakur and Sehgal, 2000; Dar and Newaj 2007). Light availability is the most important limiting factor for the performance of under-storey pasture in silvopasture systems particularly where upper storey perennial forms a dense cover storey canopy (Miah *et al.*, 1995).

Apart from forage production, silvopasture systems have the potential to offer many ecosystem services. Global climate change caused by rising levels of carbon dioxide and other greenhouse gases are recognized as a serious environmental issue of the twenty-first century. Between

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2000 and 2010, the atmospheric carbon dioxide has increased from 369 to 388 ppm, a 5.1% increase over the last 10 years, let alone 280 ppm in 1850 (Tans *et al.*, 2010). Removal of carbon from atmosphere and storing it in the terrestrial vegetation is one of climate change mitigation options, which compensate the greenhouse gas emission. Grasses are a major sink of carbon and could absorb large quantities of carbon if trees are included with grasses and judiciously managed together in the form of silvopasture systems. Thus, silvopasture systems plays an important role in sustainable production through nutrient cycling, soil and water conservation, microclimate modification and sequestering carbon in the form of wood which considered as potent instrument against climate change mitigation. Evidences are now emerging that silvopasture systems are promising land use system to increase above-ground and soil carbon stock to mitigate greenhouse gas emissions. In India, average sequestration potential in agroforestry has been estimated to be 25 t C per ha over 96 million ha (Sathaye and Ravindranath, 1998) but there is considerable variation in different regions depending upon biomass production. The role of land use systems in stabilizing the carbon dioxide levels and increasing the carbon sink potential has attracted considerable scientific attention in the recent past, especially after the Kyoto Protocol (IPCC, 2007). However, in addition to production aspects, there is also a need to quantify the ecosystem services in terms of carbon storage potential, for reducing carbon emissions for climate change mitigation. In view of this the present study was carried out to study the effect of pruning intensities and grasses on forage productivity, carbon storage, soil health and economics of Anjan tree based silvopasture systems in semiarid rainfed conditions.

MATERIALS AND METHODS

A field experiment was conducted during 2018 to 2023 on ten years old *Hardwickia binata* based silvopasture system at Central Research Farm (25°27' N latitude, 78°37' E longitude and 275 m above mean sea level) of Indian Grassland and Fodder Research Institute, Jhansi to study the effect of pruning intensities and grasses on forage productivity, carbon storage, soil health and economics of Anjan tree based silvopasture systems in semiarid rainfed conditions. The soil of the experimental field was sandy loam, low in available nitrogen and phosphorus and medium in available potash and organic carbon (Table 6). The region receives an annual rainfall of 906.5 mm and annual potential evapotranspiration of 1512 mm (Singh *et al.*, 2007). The total rainfall received was 1054.6, 714.2, 786.5, 816.8 and 1031.0 mm in 43, 54, 45, 33 and 67 rainy days during 2018, 2019, 2020, 2021 and 2022 respectively.

There were 9 treatment combinations replicated thrice

in factorial randomized block design. The treatment consisted of three pruning intensities of *H. binata* viz. 30%, 45% and 60% and establishment of three grasses viz. *Cenchrus ciliaris*, *Chrysopogon fulvus* and *Panicum maximum* in association with *H. binata*. Green crown length of trees were pruned once every year as per treatments during winter season. *H. binata* trees were uniformly established in all the experimental plots at 6 m x 6 m spacing and grasses were established in association with *H. binata* at 50 cm x 50 cm spacing.

Pruned yields of *H. binata* were recorded every year as per treatments during winter season. Grasses were harvested by tractor operated side reaper at 15 cm above the ground surface in second fortnight of September in each year. Fodder yields of grasses were recorded at the time of harvesting. Dry fodder yields were recorded in each plot on the basis of per square meter area and values were converted into tonne/ha. Dry matter yields were computed by drying 500 g plant sample of each treatment and replication in hot-air oven at 70°C.

The light transmission by the canopy of the *H. binata* under different pruning regimes and grass combinations was measured by using canopy analyzer. The light intensity above canopy (I_0) and at the ground level (I) was recorded between 12:30 and 1:00 pm. Light transmission ratio was calculated by the following formula. Measurements were conducted consequently in the month of August in each year. The light interception was measured above a canopy and beneath a canopy of different range grasses near solar noon when the light is unobstructed by cloud cover (Board *et al.*, 1992).

Tree, grass, litter, soil and total carbon stock was estimated under various pruning regimes and grasses. Carbon stock in *H. binata* trees was calculated based upon dry matter content of the tree which was calculated for various parts of *H. binata* tree using allometric equations given by Newaj *et al.*, (2014). Total dry matter of *H. binata* tree was calculated by adding dry matter of tree bole, branches, leaves and roots. The total carbon stock in tree was determined by multiplying respective dry matter of various parts with their carbon content as given by Newaj *et al.*, (2014) and then adding up the carbon stock of all the parts. The carbon stock was then calculated per hectare basis based on the tree density (278 trees/ha). In grasses, above and below ground carbon stock was calculated by multiplying above and below ground dry biomass per hectare basis with conversion factor of 0.50 (IPCC, 2006). Similarly, litter carbon stock was estimated by multiplying litter dry biomass per hectare basis with conversion factor of 0.50 (IPCC, 2006). Total system carbon stock in *H. binata* based silvopasture was determined by adding carbon stock of tree, grasses and soil per hectare basis. Soil organic car-

Table 1. Formula and Allometric equations used during study

| Formula & Allometric equations used | | Reference |
|---|-------------------------------|----------------------------|
| $\text{LTR (\%)} = \frac{I}{I_0} \times 100$ | | Board <i>et al.</i> , 1992 |
| Where, I = Light intensity received at the ground level I ₀ = Light intensity received at the top of grass canopy | | |
| Tree components | Allometric equations | Newaj <i>et al.</i> , 2014 |
| Bole | 0.232 (DBH) ^{2.046} | |
| Branch | 0.002 (DBH) ^{3.142} | |
| Leaves | 0.0002 (DBH) ^{3.514} | |
| Root | 0.036 (DBH) ^{2.337} | |
| Soil Organic Carbon stock = [Soil bulk density (g cm ⁻³) x Soil depth (cm) x Carbon (%)] x 100. | | Nelson and Sommers (1996) |

bon stock was determined up to 30 cm depth using equation given by Nelson and Sommers (1996). Soil organic carbon percentage was calculated using Walkley and Black (1934) method and soil bulk density was determined using a specific gravity method given by Singh (1980). The data obtained from the experiment were statistically analysed using the F-test.

RESULTS AND DISCUSSION

Growth parameters of *H. binata*

Pruning of branches of *H. binata* at 60% intensity attained the maximum height (9.16, 9.83, 10.37 and 11.05 m) followed by 45% pruning intensity (8.93, 9.55, 10.02 and 10.65 m) during 2nd, 3rd, 4th and 5th years of study, respectively (Table 2). While, collar diameter (23.92 cm and 25.64 cm) and diameter at breast height (19.05 cm and 20.57 cm) of *H. binata* were higher with 30% pruning intensity as compared to 45% pruning intensity (CD 23.62 cm and 25.26 cm and dbh 18.80 cm and 20.21 cm) and 60% pruning intensity (CD 23.40 cm and 24.96 cm and dbh 18.63 cm and 19.73 cm) during 4th and 5th years of experiment, respectively. Similarly, canopy spread was also significantly higher with 30% pruning intensity (4.57, 4.93 and 5.19 m) as compared to 45% pruning intensity (4.31, 4.63 and 4.81 m) and 60% pruning intensity (4.15, 4.41 and 4.3 m) during 3rd, 4th and 5th years of study respectively. Similar result was also reported by Viquez and Perez (2005). However, establishment of different grasses in association with *H. binata* did not significantly affect the growth parameters of *H. binata* during different years.

Top feed and fire wood yields of *H. binata*

The 60% pruning intensity of branches of *H. binata* recorded significantly higher top feed (TF 1.48, 1.77, 2.23, 2.68 and 3.27 t/ha) and fire wood yields (FW 2.74, 3.17, 3.49, 3.79 and 4.65 t/ha) as compared to 30% pruning intensity (TF 0.93, 1.01, 1.19, 1.55 and 2.08 t/ha and FW 1.76, 1.90, 1.98, 2.26 and 2.84 t/ha) and 45% pruning in-

tensity (TF 1.21, 1.41, 1.75, 2.15 and 2.59 t/ha and FW 2.33, 2.59, 2.82, 3.08 and 3.63 t/ha) during 1st, 2nd, 3rd, 4th and 5th years of study, respectively (Table 3). Biomass production is directly correlated with pruning intensity. Hence, severely pruned trees tended to produce more biomass as compared to lightly pruned trees. The reason is that more foliage was removed in 60% pruning intensity which increased the pruned biomass. Similar results have also been reported by Zeng (2001) and Palsaniya *et al.*; (2012). Pruning results in usage of stored reserve for its growth and production of leaves this happened because of the exposure of pruned portion to sunlight and the dormant buds become active and sprouted into shoots with the available reserves present in the trees (Muhamad and Paudyal, 1992). However, top feed and fire wood yields of *H. binata* also did not affected significantly by establishment of different grasses in association with *H. binata*.

Pasture yield

Pruning of branches of *H. binata* at 60% intensity also recorded significantly higher pasture yields (7.99, 8.40, 8.99 and 9.50 t/ha) as compared to 30% pruning intensity (7.19, 7.27, 7.38 and 7.60 t/ha) and 45% pruning intensity (7.67, 7.95, 8.33 and 8.36 t/ha) during 2nd, 3rd, 4th and 5th years respectively. Rai (2006) also found that pruning of *Acacia nilotica* and *Dalbergia sissoo* up to 50% height gave higher dry forage yield of *C. fulvus* as compared to unpruned trees in silvopasture systems. Higher biomass production under pruned treatments might be due the fact that pruning of trees facilitated more light to under-storey pasture which resulted into higher growth and yield. Light availability is the most important limiting factor for the performance of under storey pasture in silvopasture systems particularly where upper storey perennial forms a dense cover storey canopy (Miah *et al.*, 1995). Among grasses, establishment of *C. fulvus* in association with *H. binata* recorded significantly higher dry pasture yields (7.91, 8.33, 8.66, 8.93 and 9.18 t/ha) as compared to

Carbon stock of grasses

Pruning of branches of *H. binata* at 60% intensity significantly increased carbon stock of grasses (6.22 t/ha) as compared to 30% pruning intensity (4.98 t/ha) and 45% pruning intensity (5.49 t/ha) in 5th year of study (Table 5). The higher carbon stock under 60% pruning intensity was due to higher biomass yields of grasses with 60% pruning intensity as compared to 30% and 45% pruning intensity. Among grasses, *C. ciliaris* recorded significantly higher carbon stock (5.57 and 6.28 t/ha) as compared to *C. fulvus* (5.03 and 5.93 t/ha) and *P. maximum* (3.68 and 4.49 t/ha) in both initial and 5th years of experiment. The higher carbon stock of *C. ciliaris* was due to higher root-shoot ratio of *C. ciliaris* as compared to *C. fulvus* and *P. maximum*.

Litter carbon stock

30% pruning intensity of branches of *H. binata* also significantly increased litter carbon stock (0.88 and 2.10 t/ha) as compared to 45% pruning intensity (0.77 and 1.90 t/ha) and 60% pruning intensity (0.66 and 1.62 t/ha) during 1st and 5th years respectively. This may be also due higher litter biomass recorded under 30% pruning intensity of *H. binata* as compared to 45% and 60% pruning intensity. Litter carbon stock was not significantly affected by different grasses in 1st year of study (Table 5). However, in 5th year of experiment *C. fulvus* recorded significantly higher litter carbon stock (1.99 t/ha) as compared to *P. maximum* (1.74 t/ha) and it was found at par with *C. ciliaris* in association with *H. binata* (1.89 t/ha) during 5th year. This was might be due to higher litter biomass addition in soil under *C. fulvus* as compared to *P. maximum* which also resulted in higher litter carbon stock.

Soil carbon stock

Soil carbon stock was also significantly increased with

30% pruning intensity of branches of *H. binata* (26.88 t/ha) as compared to 45% pruning intensity (25.31 t/ha) and 60% pruning intensity (22.90 t/ha) in 5th year of experiment. This may be also due higher litter biomass addition in soil with 30% pruning intensity of branches of *H. binata* as compared to 45% and 60% pruning intensity. *C. fulvus* resulted in significantly higher soil carbon stock (22.99 and 25.80 t/ha) as compared to *P. maximum* (21.92 and 24.41 t/ha) and it was found at par with *C. ciliaris* (22.11 and 24.88 t/ha) during 1st and 5th years respectively. This was might be due to higher litter biomass addition in soil under *C. fulvus* as compared to *P. maximum* which also resulted in higher soil carbon stock.

Total carbon stock

Pruning intensities of branches of *H. binata* did not significantly affect the carbon stock of *H. binata* based silvopasture system in 1st year of experiment (Table 5). However, during 5th year 30% pruning intensity of branches of *H. binata* recorded significantly higher total carbon stock of the system (55.97 t/ha) as compared to 60% pruning intensity (51.00 t/ha). This may be also due higher litter biomass addition in soil under 30% pruning intensity of branches of *H. binata* as compared to 45% and 60% pruning intensity. Total carbon stock of the systems was also maximum under *C. fulvus* in association with *H. binata* (39.29 and 55.18 t/ha) followed by *C. ciliaris* (38.51 and 54.16 t/ha) and *P. maximum* (36.20 and 51.56 t/ha) during 1st and 5th years respectively. This was might be due to higher biomass production and higher litter addition in soil under *C. fulvus* as compared to *P. maximum* which resulted in higher total carbon stock of the systems.

Soil health

Pruning of branches of *H. binata* found non-significant

Table 5. Carbon stock (t/ha) in *H. binata* based silvopasture systems as influenced by pruning intensity and grasses

| Treatment | Year 1 | | | | | Year 5 | | | | |
|--------------------|--------|------|------|-------|-------|--------|------|------|-------|-------|
| | HBCS | GCS | LCS | SCS | TCS | HBCS | GCS | LCS | SCS | TCS |
| <i>Pruning (%)</i> | | | | | | | | | | |
| 30 | 10.98 | 4.68 | 0.88 | 21.85 | 37.51 | 24.11 | 4.98 | 2.10 | 26.88 | 55.97 |
| 45 | 10.72 | 4.84 | 0.77 | 22.93 | 38.49 | 23.13 | 5.49 | 1.90 | 25.31 | 53.94 |
| 60 | 11.01 | 4.75 | 0.66 | 22.24 | 38.00 | 21.88 | 6.22 | 1.62 | 22.90 | 51.00 |
| SEm± | 0.11 | 0.07 | 0.03 | 0.38 | 0.48 | 0.46 | 0.10 | 0.04 | 0.49 | 0.62 |
| CD (P=0.05) | NS | NS | 0.08 | NS | NS | 1.39 | 0.31 | 0.13 | 1.48 | 1.88 |
| <i>Grasses</i> | | | | | | | | | | |
| <i>C. ciliaris</i> | 10.83 | 5.57 | 0.78 | 22.11 | 38.51 | 22.99 | 6.28 | 1.89 | 24.88 | 54.16 |
| <i>C. fulvus</i> | 11.06 | 5.03 | 0.80 | 22.99 | 39.29 | 23.46 | 5.93 | 1.99 | 25.80 | 55.18 |
| <i>P. maximum</i> | 10.81 | 3.68 | 0.74 | 21.92 | 36.20 | 22.67 | 4.49 | 1.74 | 24.41 | 51.56 |
| SEm± | 0.11 | 0.07 | 0.03 | 0.38 | 0.48 | 0.46 | 0.10 | 0.04 | 0.49 | 0.62 |
| CD (P=0.05) | NS | 0.22 | NS | 1.14 | 1.44 | NS | 0.31 | 0.13 | NS | 1.88 |

HBCS- *H. binata* carbon stock, GCS-Grasses carbon stock, LCS- Litter carbon stock, SCS-Soil carbon stock, TCS-Total carbon stock

Table 6. Effect of pruning intensities and grasses on soil health, net return, benefit-cost ratio and sustainability yield index of *H. binata* based silvopasture systems

| Treatment | Year 1 | | | | Year 5 | | | | Year 5 | | Sustainability yield index |
|--------------------|-----------------------------|------|--------|--------|-----------------------------|------|--------|--------|-------------------|--------------------|----------------------------|
| | Available nutrients (kg/ha) | | | OC (%) | Available nutrients (kg/ha) | | | OC (%) | Net return (₹/ha) | Benefit-cost ratio | |
| | N | P | K | | N | P | K | | | | |
| <i>Pruning (%)</i> | | | | | | | | | | | |
| 30 | 225.19 | 8.21 | 211.03 | 0.571 | 271.56 | 9.96 | 245.61 | 0.688 | 39005 | 1.76 | 0.44 |
| 45 | 235.81 | 8.46 | 219.39 | 0.601 | 260.31 | 9.66 | 235.65 | 0.647 | 50263 | 1.91 | 0.52 |
| 60 | 227.17 | 8.29 | 213.78 | 0.581 | 243.89 | 9.21 | 221.61 | 0.584 | 63459 | 2.08 | 0.56 |
| SEm± | 4.31 | 0.14 | 4.08 | 0.008 | 4.71 | 0.17 | 4.40 | 0.013 | 1643 | 0.03 | 0.01 |
| CD (P=0.05) | NS | NS | NS | NS | 14.24 | 0.52 | 13.31 | 0.038 | 4968 | 0.09 | 0.02 |
| <i>Grasses</i> | | | | | | | | | | | |
| <i>C. ciliaris</i> | 226.77 | 8.26 | 212.57 | 0.581 | 257.19 | 9.57 | 233.37 | 0.637 | 49869 | 1.89 | 0.52 |
| <i>C. fulvus</i> | 238.55 | 8.54 | 221.78 | 0.601 | 266.71 | 9.78 | 240.39 | 0.660 | 53226 | 1.93 | 0.54 |
| <i>P. maximum</i> | 222.84 | 8.16 | 209.85 | 0.571 | 251.85 | 9.48 | 229.11 | 0.621 | 49633 | 1.92 | 0.45 |
| SEm± | 4.31 | 0.14 | 4.08 | 0.008 | 4.71 | 0.17 | 4.40 | 0.013 | 1643 | 0.03 | 0.01 |
| CD (P=0.05) | NS | NS | NS | NS | NS | NS | NS | NS | NS | NS | 0.02 |

for available nutrients and organic carbon in *H. binata* based silvopasture system in 1st year of experiment (Table 6). However, in 5th year of study available nitrogen (271.56 kg/ha), phosphorus (9.96 kg/ha), potash (245.61 kg/ha) and organic carbon (0.688%) were significantly increased with 30% pruning intensity of branches of *H. binata* as compared to 60% pruning intensity (N 243.89 kg/ha, P 9.21 kg/ha, K 221.61 kg/ha and OC 0.584%). This may be due higher litter biomass addition in soil under 30% pruning intensity of branches of *H. binata* as compared to 60% pruning intensity. Establishment of *H. binata* based silvopasture systems on poor shallow soil and degraded land recorded 9.11–15.50% improvement in available nutrients and organic carbon (N 12.73%, P 15.50% and K 9.11% and OC 9.47%) in 5th year of experiment than initial year (N 229.39, P 8.32 and K 214.73 kg/ha and OC 0.584%). Meena *et al.* (2023) also reported increase in organic carbon with diversified food and fodder based cropping systems over initial year. However, establishment of different grasses did not significantly affect available nutrients and organic carbon content in *H. binata* based silvopasture systems in initial and 5th years of the study.

Economics of treatments

In term of monetary return, *H. binata* based silvopasture system gave net returns ₹50,909/ha and benefit: cost ratio 1.92. Pruning of branches of *H. binata* at 60% pruning intensity recorded the maximum net return (₹63,459/ha) and benefit: cost ratio (2.08) followed by 45% pruning intensity (₹50,263/ha and 1.91) and 30% pruning intensity (₹39,005/ha and 1.76) from *H. binata* based silvopasture system (Table 6). The higher net return and benefit-cost ratio obtained from 60% pruning intensity was mainly due to higher under-storey pasture, top feed and fire wood yields

recorded under 60% pruning intensity. However, net return and benefit-cost ratio was not significantly affected by establishment of different grasses in association with *H. binata*.

Based on the results it can be concluded that 60% pruning intensity of branches of *H. binata* recorded higher light interception, production from under-storey pasture and top feed components, economic return and sustainability yield index as compared to 30% and 45% pruning intensity in silvopasture systems. However, carbon stock and nutrients and organic carbon build up in soil were higher under 30% pruning intensity in *H. binata* based silvopasture systems. Among grasses, *C. fulvus* recorded the maximum forage production, economic return, sustainability yield index, carbon stock, available nutrients and organic carbon in soil followed by *C. ciliaris* and *P. maximum* under semi-arid rainfed conditions. *H. binata* being straight growing, hardy and deep rooted, proved to be a potential tree suitable for silvopasture system on degraded lands in rainfed areas of semiarid region. Thus, *H. binata* based silvopasture system is an ideal alternate land-use option for degraded lands for higher forage production, economic return, sustainability yield index, carbon stock and nutrients and organic carbon build up in soil under semi-arid rainfed situation.

REFERENCES

- Board, J.E., Kamal, M. and Harville, B.G. 1992. Temporal importance of greater light interception to increased yield in narrow row soybean. *Agronomy Journal* **84**(4): 575–579.
- Dar, S. A. and Newaj, R. 2007. Effect of canopy pruning in *Albizia procera* on green gram (*Vigna radiata*)–wheat (*Triticum aestivum*) crop sequence. *Indian Journal of Agricultural Sciences* **78**(11): 978–980.
- IPCC. 2007. Climate change 2007: synthesis report. In: R.K. Pachauri and A. Reisinger (eds.). Contribution of Working Groups I, II and III to the Fourth Assessment Report of

- Intergovernmental Panel on Climate Change. IPCC, Geneva. IPCC. 2006. Guidelines for national greenhouse gas inventories. Institute for Global Environmental Strategies, Hayama, Kanagawa, Japan. 2006.
- Kumar, R.V., Singh, H.V., Kumar, S., Roy, A.K. and Singh, K.A. 2017. Growth and biomass production of fodder trees and grasses in a silvipasture system on non-arable land of semi-arid India. *Range Management and Agroforestry* **38**(1): 43–47.
- Meena, L.R., Meena, Samrath, Lal., Kumar, Lalit., Pillai, Nataraja Subash., Ram, T. 2023. Evaluation of food and fodder based cropping systems for sustaining productivity, resource use efficiency and profitability in western plain zone of Uttar Pradesh. *Indian Journal of Agronomy* **68**(4): 398–403. : <https://doi.org/10.59797/ija.v68i4.5462>
- Miah, M.G., Garrity, D.P. and Aragon, M.L. 1995. Light availability to the under storey annual crops in an agroforestry systems. *Ecophysiology of Tropical Intercropping* (eds. H. Sinquet and P. Cruz). INRA, Paris, pp. 99–107.
- Muhamad, N. M and Paudyal, K.B. 1992. Pruning trial for *Acacia mangium* willd. plantation in Peninsular Malaysia. *Forest Ecology and Management* **47**(1–4): 285–293.
- Nair, P.K.R., Kumar, B.M. and Nair, V.D. 2009. Agroforestry as a strategy for carbon sequestration. *Journal of Plant Nutrition and Soil Science* **172**: 10–23.
- Nelson, D.W. and Sommers, L.E. 1996. Total carbon, organic matter. pp 961-1010. In: D.L. Sparks *et al.* (Ed). Method of soil analysis. Part 3. Chemical methods. Soil Science Society of America, Madison, Wisconsin.
- Newaj, R., Dhyani, S.K., Chavan, S.B., Rizvi, R.H., Prasad, R., Ajit., Alam, B. and Handa, A.K. 2014. Methodologies for assessing biomass, carbon stock and carbon sequestration in agroforestry systems. National Research Centre for Agroforestry, Jhansi, 62 p.
- Palsaniya, D.R., Singh, H.K., Ram, M., Rai, P., Singh, U.P. and Yadav, R.S. 2012. Effect of pruning on growth and forage production in *Albizia procera* based silvipastoral system in semi-arid Bundelkhand, India. *Range Management and Agroforestry* **33**(1): 96–98.
- Rai, P. 2006. Pasture stability after twelve years of establishment under pure pasture and silvipastoral system. *Range Management and Agroforestry* **27**(2): 66–69.
- Rosso, F. and Ninin, P. 1998. Variabilidad de los defectos de trozas de la especie teca (*Tectona grandis*) en diferentes densidades arbóreas, en la Unidad Experimental de la Reserva Forestal de Ticoporo, Barinas-Venezuela. *Revista Forestal Venezolana* **42**(2): 103–112.
- Sathaye, J.A. and Ravindranath, N.H. 1998. Climate change mitigation in the energy and forestry sectors of developing countries. *Annual Review Energy Environment* **23**: 387–437.
- Sharma K.C. 2014. Production potential of fodder crops sequences in association with ber (*Ziziphus mauritiana* Lamk.) under agri-horticulture system in hot arid ecosystem of western India. *Range Management and Agroforestry* **35**: 188–192.
- Singh, J.B., Behari, P. and Yadav, R.B. 2007. On the estimation of evapotranspiration, water-use efficiency and crop coefficient of lucerne (*Medicago sativa* L.) in central India. *Current Science* **93**: 1,719.
- Singh, R.A. 1980. Soil physical analysis. Kalyani Publishers, New Delhi.
- Soni, M.L., Yadava, N.D., Beniwal, R.K., Singh, J.P., Kumar, S. and Birbal. 2013. Grass based strip cropping systems for controlling soil erosion and enhancing system productivity under drought situations of hot arid western Rajasthan. *International Journal of Agricultural and Statistical Science* **9**: 685–692.
- Tans, P.P., Fung, I.Y. and Takahashi, T. 2010. Observation constraints on the global atmospheric CO₂ budget. *Science* **247**: 1,431–1,438.
- Thakur, P.S. and Sehgal, S. 2000. Effect of canopy management on root parameters in agroforestry tree species of temperate region. *Indian Journal of Agroforestry* **2**: 75–78.
- Verma, Kamlesh., Prasad, S.K., Singh, M.K., Sharma Prashant, 2023. Response of alley-cropped pearl millet (*Pennisetum glaucum*) to nitrogen and zinc schedules under semi-arid regions. *Indian Journal of Agronomy* **68**(1): 105–109. <https://doi.org/10.59797/ija.v68i1.213>.
- Viquez, E. and Perez, D. 2005. Effect of pruning on tree growth, yield, and wood properties of *Tectona grandis* plantations in Costa Rica. *Silva Fennica* **39**(3): 381–390.
- Walkley, A.J. and Black, A. 1934. Estimation of soil organic carbon by chronic acid titration method. *Soil Science* **37**: 29–38.
- Zeng, B. 2001. Pruning Chinese Tree: an experimental and modeling approach. *Tekst-Proefschrift Universiteit Utrecht* **173**: 135–144.

Evaluation of barnyard millet intercropping systems in semi-arid zone of Hisar

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ABSTRACT

A field experiment was conducted at CCSHAU, Hisar during *Kharif seasons* of 2021–22 and 2022–23 in three times replicated randomized block design. The experiment was comprised of thirteen barnyard millet-based intercropping systems in replacement series with greengram and sesame as intercrop with row ratio of 5:1, 4:2, 3:3, 2:4, 1:5 in addition to their sole crops. Results revealed that the barnyard millet intercropped with greengram was found superior over sole barnyard millet in terms of different intercropping indices. But, barnyard millet intercrop with sesame was found uneconomical. The barnyard millet + greengram (1:5) recorded the highest land equivalent ratio (LER; 1.25), barnyard millet equivalent yield (BMEY; 2977 kg/ha), land use efficiency (LUE; 119.4%), area time equivalent ratio (ATER; 1.14), relative crowding coefficient (RCC; 1.79), monetary advantage index (MAI; ₹ 10,756/ha), system productivity index (SPI; 2903), intercropping advantage index (IAI; 34.6), net return (₹ 23,111/ha), benefit:cost (1.42) and per day return (₹ 300.3) which was closely followed by barnyard millet + greengram (4:2). Hence, barnyard millet + greengram (1:5) intercropping system is a suitable option for achieving higher monetary returns and resource use efficiency as compared to sole barnyard millet under semiarid region of India.

Key words: Intercropping, Barnyard millet, Greengram, Sesame and Row ratio

Millets cultivation spread over 74 Mha of the globe with the production of millets is 89.17 million metric tonnes (FAO, 2022). India is the global leader in production of millet with a share of ~15% of the world's total production. In India, millets are cultivated majorly in 21 states over an area of 12.53 Mha, with production of 15.53 mt and productivity of 1237 kg/ha (FAO, 2022). Barnyard millet (*Echinochloa frumentacea*) is fourth most important minor millet, providing food security to many poor people across the world. In India, it is mainly cultivated in Orissa, Maharashtra, Madhya Pradesh, Tamil Nadu, Bihar, Punjab, Gujarat and hills of Uttarakhand (Kumar *et al.*, 2000). Barnyard millet is the minor millet which is emerged as very essential dual-motive crop for feed and fodder. Despite barnyard millet's excellent nutritional and agronomic value, the lack of awareness has led this crop to be considered a neglected and underutilized crop. Low productivity of millets as compared to other cereal crops is also a reason for low interest of farmers about the millet's cultiva-

tions. The intercropping of millets with legumes can enhance the economic returns per unit area. Intercropping is considered the most suitable for sustaining crop productivity (Buttar *et al.*, 2023). Cereal association with legumes and oilseeds in polyculture is always noteworthy in terms of multiple benefits (Singh *et al.*, 2021). Furthermore, millets are suitable candidates for mixed and intercropping and offer the sustainable uses of natural resources and play a crucial role in improving the livelihood security of small marginal grower of the rainfed areas (Singh *et al.*, 2022). Intercropping is a beneficial system of crop production aimed at maximizing production and profits by effectivity utilizing the nutrients and water, and other resources (Kumar *et al.*, 2022; Ajibola and Kolawole, 2019). Growing cereals as sole crop is not a remunerative venture in present scenario, hence there is need to integrate pulses and oilseeds in cereals production system to fulfill food and nutritional demand of rapid growing population (Avasthe *et al.*, 2023). But success of intercrops depend on ultimate density, planting date, resources availability, soil and crop management practices and intercropping models (Kumar *et al.*, 2022; Singh *et al.*, 2021). Spatial arrangement and plant population in an intercropping system have important effects on the balance of competition between component crops and their overall productivity. It was hypothesized that the intercropping of barnyard millet with green gram

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and sesame may be robust option for yield enhancement because of their diverse morphology, growth rate and similar climatic requirements and such intercropping systems are quite popular in India. Therefore, current study was conducted to assess the effect of different inter cropping combination on farm productivity and profitability under semi-arid condition of India.

MATERIALS AND METHODS

A field experiment was carried out at CCS Haryana Agricultural University, Hisar, Haryana, India (29°10' N latitude, 75°46' E longitude and 215.2 M altitude) during *Kharif* season of 2022 and 2023 in three times replicated randomized block design. The experiment was comprised of thirteen treatments to evaluate barnyard millet based intercropping systems taking green gram and sesame as intercrop with barnyard millet + greengram/sesame with row ratio of 5:1, 4:2, 3:3, 2:4, 1:5 in addition to their sole crop. Experimental soil was sandy loam in texture, slightly alkaline in pH (7.6), low in organic carbon (0.38%), medium in available phosphorus (21.6 kg/ha), and low in available nitrogen (198 kg/ha) and available potassium (248 kg/ha). The maximum and minimum temperatures during the crop study period were congenial for the growth and development of crops. Sowing of sole and intercrops was done at 30 cm row to row distance. In intercropping treatments, barnyard millet rows were replaced with intercrops as per treatments in various row ratio of barnyard millet + intercrop varying from 5:1, 4:2, 3:3, 2:4 and 1:5. Barnyard millet variety VC 27 was intercropped with green gram (MH 1871) and sesame (HT 2). Crop was fertilized with 40 kg N/ha and 40 kg P₂O₅. Half dose of nitrogen along with full quantity of phosphorus was applied at the time of sowing. Remaining half quantity of nitrogen was applied at 25-30 days after sowing. Other crop management practices were followed as per the recommended package of practices. The economic yield of different crops was converted into barnyard millet equivalent yield (BEY) based on prevailing market price. Other input and output prices for economical calculation were used as given by department of agricultural economics, CCS Haryana Agricultural University, Hisar. Different indices like the relative yield, competitiveness, land use and economic performance of different intercropping systems were calculated and presented based on pooled analyzed data from two years as follows:

Relative Crowding Coefficient (RCC or K): It is a measure of the relative dominance of one species over the other in a mixture. The K was calculated as:

$$K = (K_M \times K_I)$$

$$K_M = Y_{mi} \times Z_{im} / ((Y_m - Y_{mi}) \times Z_{mi})$$

$$K_I = Y_{im} \times Z_{mi} / ((Y_i - Y_{im}) \times Z_{im})$$

where Z_{mi} and Z_{im} were the proportions of main crop

and intercrop in the mixture, respectively. When the value of K is greater than 1, there is a yield advantage; when K is equal to 1, there is no yield advantage; and when it is less than 1, there is a disadvantage.

Aggressivity (A): The aggressivity was formulated as follows

$$A_{intercrop} = (Y_{im}/Y_i \times Z_{im}) - (Y_{mi}/Y_m \times Z_{mi})$$

$$A_{maincrop} = (Y_{mi}/Y_m \times Z_{mi}) - (Y_{im}/Y_i \times Z_{im})$$

Competitive Ratio (CR): The CR gives a better measure of competitive ability of the crops and is also advantageous as an index over K and A. The CR represents the ratio of individual LERs of the two component crops and considers the proportion of the crops in which they are initially sown. The CR is calculated according as per the following formula.

$$CR_{maincrop} = (LER_{maincrop} / LER_{intercrop}) (Z_{intercrop-maincrop} / Z_{maincrop-intercrop})$$

$$CR_{intercrop} = (LER_{intercrop} / LER_{maincrop}) (Z_{maincrop-intercrop} / Z_{intercrop-maincrop})$$

$Z_{intercrop}$ and $Z_{maincrop}$ are the proportional sown area under inter and main crop in intercropping, respectively.

Actual Yield Loss (AYL): The AYL was calculated with the following equation.

$$AYL = AYL_{maincrop} + AYL_{intercrop}$$

$$AYL_{maincrop} = ((Y_{mi}/Z_{mi}) / (Y_m/Z_m)) - 1$$

$$AYL_{intercrop} = ((Y_{im}/Z_{im}) / (Y_i/Z_i)) - 1$$

Land Equivalent Ratio (LER)

$$LER = \sum_i^m \frac{Y_i}{Y_{ij}}$$

Y_i = Individual crop yield under intercropping system

Y_{ij} = Individual crop yield under sole cropping system

Land Equivalent Coefficient (LEC)

$$LEC = LA \times LB$$

Where, LA = LER of main crop

LB = LER of intercrop

Area Time Equivalent Ratio (ATER): It considers the duration of the crops and permits an evaluation of crops on yield per day basis.

$$ATER = \frac{L_A \times T_A + L_B \times T_B}{T}$$

Where, L_A and L_B are partial LER of component crops A and B, T_A and T_B are duration of crops A and B and T is the total duration of the intercropping system.

Crop Performance Ratio (CPR): The CPR was calculated with the following equation. The CPR for species X, in an intercrop composed of species X and Y,

$$CPR_x = Y_{ix} / (P_{ix} \times Y_{sx})$$

Where Y_{ix} and Y_{sx} are its yields per unit area ($g\ m^{-2}$) in the intercrop and sole crop respectively, and P_{ix} is the proportional sown area of species X in the intercrop.

$$CPR_y = Y_{iy} / (P_{iy} \times Y_{sy})$$

Where Y_{iy} and Y_{sy} are its yields per unit area (g m^{-2}) in the intercrop and sole crop respectively, and P_{iy} is the proportional sown area of species Y in the intercrop.

$$\text{Total CPR}_{xy} = Y_{ix} + Y_{iy} / (P_{ix} * Y_{sx}) + (P_{iy} * Y_{sy})$$

Where Y_{ix} , Y_{sx} , P_{ix} , Y_{iy} , Y_{sy} and P_{iy} are as defined previously.

Income Equivalent Ratio (IER): It is calculated by the following formula.

$$\text{IER} = \frac{\text{Net return in intercropping system}}{\text{Net return in sole cropping system}}$$

Monetary Advantage Index (MAI): It is an index which tells the relative money value of produce under inter-cropping system.

$$\text{MAI} = \text{Value of combined yield of intercrop} \times \frac{\text{LER} - 1}{\text{LER}}$$

Where, LER is land equivalent ratio.

System Productivity Index (SPI): This was calculated with the following expression

$$\text{SPI} = (\text{SA} / \text{LB} \times \text{Lb}) + \text{Sa}$$

Where: SPI = System productivity index,

SA and LB = Mean yield of main crop and intercrop in sole cropping,

Sa and Lb = Yield of main crop and inter crop in inter-cropping.

Land use efficiency (LUE):

$$\text{LUE} = (\text{LER} + \text{ATER}) \times 100/2$$

Intercropping Advantage Index (IAI):

$$\text{IAI}_{\text{main crop}} = \text{AYL}_{\text{maincrop}} P_{\text{maincrop}}, \text{ and } \text{IAI}_{\text{intercrop}} = \text{AYL}_{\text{intercrop}} P_{\text{intercrop}}$$

$$\text{IAI}_{\text{Total}} = \text{IAI}_{\text{maincrop}} + \text{IAI}_{\text{intercrop}}$$

Where, P_{maincrop} and $P_{\text{intercrop}}$ are the commercial value of main crop and intercrop, respectively

Relative Net Returns Index (RNRI) (Jain and Rao, 1980):

$$\text{RNRI} = ((P_i Y_i) + (P_j Y_j) \pm D_{ij}) / (P_i Y_{ii})$$

Where, Y_i - Yield of the i^{th} major crop ha^{-1} , Y_j - Yield of the j^{th} intercrop ha^{-1} , P_i - Unit price of the product of i^{th} major crop, P_j - Unit price of the product of j^{th} intercrop, Y_{ii} - Yield of i^{th} sole crop ha^{-1} and D_{ij} - Differential cost of cultivation of ij^{th} crop combination in comparison to i^{th} sole crop.

Barnyard millet Equivalent yield (CEY): CEY was calculated to compare system performance by converting the yield of non-barnyard millet crops into equivalent barnyard millet yield on a price basis, using the formula

$$\text{CEY} = Y_x (P_x / P_r)$$

where Y_x is the yield of non-barnyard millet crops (q ha^{-1}), P_x is the price of non-barnyard millet crop (₹ q^{-1}) and P_r is the price of barnyard millet.

The observations recorded during the course of investigation were tabulated and subjected to analysis of variance

techniques as described by Gomez and Gomez (1984).

RESULTS AND DISCUSSION

Barnyard millet seed yield and inter crop yield: Intercropping of greengram and sesame in replacement series with barnyard millet has significantly reduced the barnyard millet seed yield as compared to sole barnyard millet (Table 1). Irrespective of row ratios, sesame intercrop with barnyard millet recorded higher seed yield reduction as compared to barnyard millet intercrop with greengram. Irrespective of intercrops, intercropping of barnyard millet + intercrop in 5:1 and 1:5 row ratios recorded significantly lower and higher seed yield loss over sole barnyard millet, respectively. Intercropping of barnyard millet with greengram was found effective over barnyard millet + sesame intercropping at all row ratios. Replacement of barnyard millet with green gram in intercropping with row ratio of 5:1 to 1:5 reduced the seed yield of barnyard millet by 9.2 to 57.5%, while replacement of barnyard millet with sesame in intercropping with row ratio 5:1 to 1:5 resulted in 16.7 to 66.1% seed yield reduction of barnyard millet as compared to sole barnyard millet crop. Higher sole crop yield as compared to the intercrop under different crop combinations under different agro condition was also reported by Baldev *et al.* (2003) and Anishetra and Kalaghatagi (2020). Concerning to inter crop yield, seed yield of both intercrops in intercropping with barnyard millet at all row ratios of combination declined significantly over their sole planting (Table 1). Barnyard millet + greengram intercropping row ratios from 5:1 to 1:5 resulted in 90.5 to 25.5% reduction in seed yield of greengram over sole greengram crop. Replacement of sesame in with barnyard millet + from 5:1 to 1:5 row ratio declined sesame seed yield by 88.4 to 27.3% over sole sesame crop, respectively. These results were also in conformity with findings of Padhi *et al.* (2010).

Barnyard millet Equivalent Yield (BEY): Intercropping of barnyard millet with greengram and sesame affected barnyard millet equivalent yield significantly (Table 1). Among intercrops, greengram as sole and intercropping with barnyard millet recorded significantly higher BEY than sole barnyard millets which may be due to its higher market price and yield obtained compared to sesame. Sesame as sole crop and intercrop with barnyard millet at all row ratios recorded significantly lower BEY than sole barnyard millet crop. Among all intercropping systems, barnyard millet + greengram (1:5) recorded highest BEY (2977 kg/ha) (Table 1), which was 26.9% higher than sole barnyard millet crop. Anishetra and Kalaghatagi (2020), also recorded significantly higher sesame equivalent yield with sesame + foxtail millet of 2:4 (703 kg/ha). These results are also corroborated with the findings of Kiranmai

et al. (2021) and Choudhary (2012).

Land use efficiency (LUE) and land equivalent coefficient (LEC): Significant variation among intercropping systems was found regarding LUE and LEC (Table 1). Barnyard millet intercrop with greengram with all row ratios recorded LUE more than hundred, which showed better and efficient use of land as a resource in intercropping compared to sole planting. Barnyard millet + sesame intercrop with all row ratios except barnyard millet + sesame (1:5) recorded LUE less than hundred, hence found uneconomical. Irrespective of row ratios, barnyard millet intercrop with greengram recorded higher LEC than barnyard millet + sesame intercropping among other intercropping systems, barnyard millet + green gram (1:5) closely followed by barnyard millet + green gram (2:4) recorded significantly higher LUE (119.4 percent) and LEC (0.37). Higher land use efficiency of lupine +wheat (75:100 ratio) followed by lupine +finger millet mixtures (75:100 ratios) was also reported by Yayeh et al. (2014). Higher productivity of intercropping over sole cropping was also reported by Kumar et al. (2023).

Land equivalent ratio (LER) and area-time equivalency ratio (ATER): LER and ATER were significantly affected with intercropping systems (Tables 1 and 2). Irrespective to intercrops, LER for barnyard millet crop was declined with decline in plant population compared to intercrop. Higher LER for barnyard millet (0.91 and 0.85) was recorded with row ratio of 5:1 when barnyard millet was intercropped with greengram and sesame, respectively, which may be due to higher barnyard millet yield in these intercropping treatments compared to others. Higher LER for intercrop (0.82 and 0.71) was recorded with row ratio of 1:5 when barnyard millet was intercrop with greengram and sesame, respectively. Intercropping of barnyard millet with greengram with all row ratios was recorded with LER values more than one, hence proved more economical than sole planting of barnyard millet. Barnyard millet intercrop with sesame in all row combinations except 1:5 recorded LER less than one, hence uneconomical over sole barnyard millet crop. Similarly, intercropping of barnyard millet with greengram with all row ratios was recorded with ATER values more than one, while Barnyard millet intercropping with sesame in all row combinations recorded ATER less than one, hence found uneconomical over sole barnyard millet. Among all the intercropping systems, barnyard millet + green gram (1:5) closely followed by barnyard millet + green gram (2:4) recorded significantly higher LER (1.25) and ATER (1.14). This might be because component crops differed in utilizing growth and other resources and converting them into sink more efficiently resulting in higher yield per unit area compared to sole crop. Anishetra and Kalaghatagi (2020) reported that

Table 1. Yield performance and Land use intercropping indices of Barnyard millet-based intercropping systems.

| Treatments | Seed yield (kg ha ⁻¹) | | Biological yield (kg ha ⁻¹) | | Land Equivalent Ratio (LER) | | Barnyard millet Seed Equivalent yield (kg ha ⁻¹) | Land Use Efficiency (LUE %) | Land Equivalent Coefficient (LEC) |
|----------------------------|-----------------------------------|------------|---|------------|-----------------------------|------------|--|-----------------------------|-----------------------------------|
| | Barnyard millet | Inter crop | Barnyard millet | Inter crop | Barnyard millet | Inter crop | | | |
| Sole Barnyard millet | 2345 | | 15179 | | | | 2345 | | |
| Sole Greengram | | 804 | | 3352 | | | 2659 | | |
| Sole Sesame | | 538 | | 3095 | | | 1795 | | |
| Barnyard + Greengram (5:1) | 2,130 | 76 | 13580 | 394 | 0.91 | 0.11 | 2380 | 101.2 | 0.10 |
| Barnyard + Greengram (4:2) | 1,889 | 144 | 11668 | 709 | 0.81 | 0.21 | 2364 | 100.0 | 0.17 |
| Barnyard + Greengram (3:3) | 1,535 | 291 | 9703 | 1291 | 0.65 | 0.43 | 2496 | 105.6 | 0.27 |
| Barnyard + Greengram (2:4) | 1,282 | 458 | 7565 | 1930 | 0.55 | 0.65 | 2796 | 115.7 | 0.37 |
| Barnyard + Greengram (1:5) | 997 | 599 | 5520 | 2525 | 0.43 | 0.82 | 2977 | 119.4 | 0.37 |
| Barnyard + Sesame (5:1) | 2,001 | 62 | 12494 | 446 | 0.85 | 0.12 | 2207 | 87.6 | 0.10 |
| Barnyard + sesame (4:2) | 1,781 | 105 | 10949 | 747 | 0.76 | 0.21 | 2131 | 88.0 | 0.15 |
| Barnyard + sesame (3:3) | 1,435 | 185 | 8824 | 1237 | 0.61 | 0.35 | 2050 | 89.5 | 0.22 |
| Barnyard + Sesame (2:4) | 1,122 | 286 | 6761 | 1759 | 0.48 | 0.52 | 2076 | 94.6 | 0.25 |
| Barnyard + Sesame (1:5) | 794 | 391 | 4859 | 2303 | 0.34 | 0.71 | 2096 | 101.2 | 0.24 |
| CD (5%) | 76 | | 1289 | | 0.03 | 0.16 | 327 | 5.1 | 0.10 |
| SEm (±) | 25 | | 434 | | 0.01 | 0.05 | 111 | 1.7 | 0.03 |

Table 2. Area Time Equivalent Ratio and Competition intercropping indices for Barnyard millet-based intercropping systems.

| Treatments | ATER | | CPR | | System | | Aggressivity (A) | | RCC | | Competitive Ratio | | Actual Yield Loss (AYL) | | | |
|----------------------------|-----------------|-----------|-----------------|-----------|--------|-----------------|------------------|--------------------------------------|--------------------------------|--|-------------------|-----------|-------------------------|-----------|-------|-------|
| | Barnyard millet | Intercrop | Barnyard millet | Intercrop | System | Barnyard millet | Intercrop | K _{CP} (Barnyard millet) | K _{IM} (Intercrop) | K = K _{int} * K _{IM} | Barnyard millet | Intercrop | Barnyard millet | Intercrop | Total | |
| Sole Barnyard millet | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - |
| Sole Greengram | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - |
| Sole Sesame | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - |
| Barnyard + Greengram (5:1) | 0.91 | 0.10 | 1.00 | 0.64 | 1.06 | 0.68 | -0.68 | 2.21 | 0.64 | 1.49 | 1.99 | 0.60 | 0.09 | -0.35 | -0.26 | -0.26 |
| Barnyard + Greengram (4:2) | 0.81 | 0.18 | 0.99 | 0.63 | 1.11 | 0.62 | -0.62 | 2.14 | 0.57 | 1.19 | 2.34 | 0.52 | 0.20 | -0.37 | -0.17 | -0.17 |
| Barnyard + Greengram (3:3) | 0.65 | 0.38 | 1.03 | 0.85 | 1.17 | 0.40 | -0.40 | 1.91 | 2.52 | 3.69 | 1.91 | 0.68 | 0.31 | -0.14 | 0.16 | 0.16 |
| Barnyard + Greengram (2:4) | 0.55 | 0.57 | 1.12 | 0.97 | 1.36 | 0.18 | -0.18 | 2.51 | 0.08 | -0.62 | 1.93 | 0.58 | 0.66 | -0.03 | 0.63 | 0.63 |
| Barnyard + Greengram (1:5) | 0.43 | 0.72 | 1.14 | 0.99 | 1.59 | 0.26 | -0.26 | 4.02 | 0.43 | 0.79 | 2.81 | 0.39 | 1.52 | -0.01 | 1.51 | 1.51 |
| Barnyard + Sesame (5:1) | 0.66 | 0.12 | 0.78 | 0.70 | 1.01 | 0.55 | -0.55 | 1.28 | 0.68 | 0.82 | 1.48 | 0.71 | 0.03 | -0.30 | -0.27 | -0.27 |
| Barnyard + sesame (4:2) | 0.59 | 0.21 | 0.79 | 0.63 | 1.08 | 0.55 | -0.55 | 1.65 | 0.53 | 0.82 | 1.93 | 0.55 | 0.13 | -0.37 | -0.24 | -0.24 |
| Barnyard + sesame (3:3) | 0.47 | 0.35 | 0.83 | 0.70 | 1.12 | 0.36 | -0.36 | 1.59 | 0.55 | 0.86 | 1.76 | 0.58 | 0.22 | -0.29 | -0.07 | -0.07 |
| Barnyard + Sesame (2:4) | 0.37 | 0.52 | 0.89 | 0.78 | 1.25 | 0.21 | -0.20 | 1.86 | 0.55 | 1.02 | 1.86 | 0.55 | 0.45 | -0.22 | 0.23 | 0.23 |
| Barnyard + Sesame (1:5) | 0.26 | 0.71 | 0.97 | 0.86 | 1.42 | 0.24 | -0.24 | 2.60 | 0.55 | 1.38 | 2.45 | 0.43 | 1.00 | -0.14 | 0.85 | 0.85 |
| CD (5%) | 0.03 | 0.14 | 0.15 | 0.08 | 0.21 | 0.15 | 0.14 | 0.45 | 0.45 | 0.18 | 0.50 | 0.06 | 0.12 | 0.06 | 0.30 | 0.30 |
| SEM (±) | 0.01 | 0.05 | 0.05 | 0.64 | 0.07 | 0.05 | 0.05 | 0.15 | 0.15 | 0.06 | 0.17 | 0.02 | 0.04 | 0.02 | 0.10 | 0.10 |

intercropping of sesame + foxtail millet in 2:4 ratio recorded significantly higher LER (1.33) and ATER (1.28) compared to sole crops. The intercropping systems recorded with LER values less than 1.0 indicates the disadvantage of intercropping (Dass and Sudhishri, 2010, Habib *et al.*, 2016).

Relative crowding coefficient (RCC): Relative crowding coefficient is a measure of the relative dominance of one species over the other in a mixture. RCC was significantly affected by intercropping systems (Table 2). Barnyard millet recorded higher RCC values than intercrops at all row ratios of intercropping except barnyard millet + greengram (3:3) which shows the higher competitive ability and relative dominance of barnyard millet over intercrops. Among all intercropping systems, barnyard millet + greengram at all row ratios except 2:4 recorded higher RCC values over barnyard millet intercropping with sesame. Barnyard millet + greengram (3:3) closely followed by barnyard millet + greengram (1:5) with significantly higher system RCC values of 4.89 and 1.79, respectively. Among intercropping systems, barnyard millet + sesame intercropping with row ratio of 5:1, 4:2 and 3:3 was found non-advantageous as RCC of system recorded values less than one, while barnyard millet intercrop with greengram was recorded with system RCC values more than one at all row ratios. Varia and Sadhu (2011) also reported higher RCC value with pearl millet + greengram intercropping.

Competitive ratio (CR): Competitive ratio was significantly affected by intercropping treatments (Table 2). In intercropping systems, Barnyard millet recorded higher CR values compared to intercrops at all row ratios, which shows competitive nature of barnyard millet over intercrops (greengram and sesame). Barnyard millet intercrop with green gram recorded higher CR values compared to barnyard millet intercrop with sesame. Regarding relative competitiveness with barnyard millet, sesame as intercrop proved more competitive than green gram intercropping row ratio of 5:1, 4:2 and 1:5, while at 3:3 and 2:4 row ratio of intercropping of Barnyard millet + green gram proved more competitive than sesame. Among all intercropping systems, barnyard millet + green gram (1:5) followed by barnyard millet + sesame (1:5) was recorded with significantly higher CR_{barnyard millet} (2.81), while maximum CR_{intercrop} (0.71) was recorded by barnyard millet + sesame (5:1). Similar finding was also reported by Jakhar *et al.* (2015).

Aggressivity (A): Aggressivity was significantly affected with intercropping systems (Table 2). Barnyard millet recorded positive A values with all row ratios, while both intercrops recorded negative A values, which indicated more dominance and aggressivity of barnyard millet over greengram and sesame in intercropping. Higher A values

for barnyard millet recorded in intercropping with greengram compared to barnyard millet + sesame intercropping showed that Barnyard millet was more aggressive or dominant with greengram than sesame. Among all intercropping systems, barnyard millet + green gram (5:1) followed by barnyard millet + green gram (4:2) was recorded with significantly higher values both for barnyard millet (+ 0.68) and intercrop (- 0.68), respectively (Table 2). Shalini *et al.* (2019) also reported that the aggressivity values for finger millet in finger millet + black gram and finger millet + pigeonpea intercropping at 3:2, 4:2, 5:2 and 6:2 row ratios were found negative which indicate that both the pulses have shown dominance over finger millet. While, Jakhar *et al.* (2015) studied the performance of finger millet and groundnut-based strip intercropping in ratios 6:4, 8:4, 10:4 and 12:4 and found negative aggressivity (A) values for groundnut which indicated that finger millet has shown dominance over groundnut. Similar trend was also observed by Ram and Meena (2014).

Actual yield loss (AYL) and crop performance ratio (CPR): AYL and CPR were significantly affected with intercropping systems (Table 2). $AYL_{\text{barnyard millet}}$ had positive values in intercropping with greengram and sesame at all row combinations, while negative $AYL_{\text{intercrop}}$ values were recorded in all intercropping systems with both intercrops. All barnyard millet-based intercropping systems with green gram and sesame except barnyard millet + green gram (5:1 and 4:2), barnyard millet + sesame (5:1, 4:2 and 3:3) recorded negative values of total AYL. Irrespective of row ratios CPR barnyard millet was recorded higher in barnyard + greengram intercropping as compared to barnyard millet + sesame intercropping. CPR for barnyard millet was increased with decline in number of rows compared to intercrop, while CPR for intercrop was increased with increase in number of rows compared to barnyard millet i.e. from 5:1 to 1:5 (Barnyard millet + intercrop). Among all intercropping systems, barnyard millet + green gram (5:1) recorded total AYL value more than one (1.51) and recorded significantly higher CPR system (1.59), maximum CPR barnyard millet (2.52) and $CPR_{\text{intercrop}}$ (0.99), which indicated an increment of 59 percent in crop performance in intercropping compared to barnyard millet as sole crop. Quantification of yield loss or gain due to intercropping with other species or the variation of the plant population could not be obtained through partial LERs, whereas partial AYL shows the yield loss or gain by its sign and as well as its value (Banik *et al.*, 2000).

Monetary advantage index (MAI) and system productivity index (SPI): Intercropping systems significantly affected MAI and SPI (Table 3). Intercropping of barnyard millet with green gram recorded positive MAI values with all row combinations, while barnyard millet + sesame intercrop-

ping resulted negative MAI values at all row ratios except Barnyard millet + sesame (2:4 and 1:5), which showed relative monetary advantage of barnyard millet + greengram over barnyard millet + sesame intercropping. Barnyard millet intercrop with greengram recorded higher SPI than barnyard millet + sesame intercropping at all row ratios. Among intercropping systems, barnyard millet + green gram (1:5) followed by barnyard millet + greengram (2:4) recorded significantly higher MAI (10,756 ha⁻¹) and SPI (2903) (Table 3). Higher SPI in intercropping systems was also reported by Gupta *et al.* (2019) and Ahlawat and Gangaiah (2010).

Intercropping advantage index (IAI) and relative net returns index (RNRI): Intercropping systems significantly affected IAI and RNRI (Table 3). Barnyard millet intercropping with greengram and sesame recorded negative values of IAI at all row ratios except barnyard millet + greengram (4:2 and 1:5) and barnyard millet + sesame (1:5), which showed relative advantage of barnyard millet intercrop with greengram and sesame with these row ratios. Irrespective to row ratios barnyard millet + greengram recorded higher values of IAI compared to barnyard millet + sesame intercropping, which showed that greengram is more advantageous as intercrop with barnyard millet compared to sesame. Barnyard millet + greengram recorded RNRI values more than one at all row ratios except 5:1, while barnyard millet intercrop with sesame recorded RNRI less than one at all row ratios. Among intercropping systems, barnyard millet + green gram (1:5) followed by barnyard millet + greengram (2:4) and barnyard millet + sesame (1:5) recorded significantly higher IAI (34.6) and RNRI (1.23) (Table 3). The higher IAI is also an indicator of the economic feasibility of intercropping systems.

Relative economic efficiency (REE) and income equivalent ratio (IER): REE and IER were significantly affected by intercropping systems (Table 3). Barnyard millet intercrop with greengram and sesame recorded negative values of REE at all row ratios except barnyard millet + greengram (4:2 and 1:5). Similarly, except barnyard millet + greengram (4:2 and 1:5), all intercropping systems reported with IER values less than one, which showed relative higher economic efficiency and monetary returns of barnyard millet + greengram (4:2 and 1:5). Barnyard millet intercrop with greengram proved economical as it was recorded with higher values of REE and IER compared to barnyard millet intercrop with sesame. Among intercropping systems, barnyard millet + green gram (1:5) followed by barnyard millet + greengram (2:4) recorded significantly higher REE (22.1%) and IER (1.22).

Economics: Cost of cultivation (total and variable) for barnyard millet intercrop with greengram or sesame intercropping was less than sole barnyard millet crop (Table 3).

Table 3. System Productivity Index and Economics of Barnyard millet-based intercropping systems.

| Treatments | VC (ha ⁻¹) | TC (ha ⁻¹) | Gross return (ha ⁻¹) | Net Return (ha ⁻¹) | BCR | VCR | Per day return (ha ⁻¹ day ⁻¹) | MAI (ha ⁻¹) | RNRI | REE (%) | System Productivity Index (SPI) | Intercropping Advantage Index (IAI) | Income Equivalent Ratio (IER) |
|----------------------------|---------------------------|---------------------------|--|--------------------------------------|------|-------|--|----------------------------|------|------------|---------------------------------------|---|-------------------------------------|
| Sole Barnyard millet | 28868 | 58168 | 78203 | 20036 | 1.34 | 0.34 | 260.0 | | | | | | |
| Sole Greengram | 26585 | 55428 | 63649 | 8221 | 1.15 | 0.15 | 126.7 | | | | | | |
| Sole Sesame | 25758 | 54435 | 43456 | -10979 | 0.80 | -0.20 | -106.3 | | | | | | |
| Barnyard + Greengram (5:1) | 28469 | 57674 | 76696 | 19023 | 1.33 | 0.33 | 247.0 | 774 | 1.01 | -1.9 | 2384 | -25.3 | 0.98 |
| Barnyard + Greengram (4:2) | 28098 | 57236 | 73422 | 16187 | 1.28 | 0.28 | 210.3 | 189 | 0.99 | -14.3 | 2369 | -24.1 | 0.86 |
| Barnyard + Greengram (3:3) | 27726 | 56798 | 73812 | 17014 | 1.30 | 0.30 | 220.7 | 2828 | 1.04 | -12.5 | 2525 | -3.9 | 0.88 |
| Barnyard + Greengram (2:4) | 27328 | 56304 | 76777 | 21373 | 1.38 | 0.38 | 277.0 | 8069 | 1.16 | 12.5 | 2789 | 13.0 | 1.12 |
| Barnyard + Greengram (1:5) | 26957 | 55866 | 78976 | 23111 | 1.42 | 0.42 | 300.3 | 10756 | 1.23 | 22.1 | 2903 | 34.6 | 1.22 |
| Barnyard + Sesame (5:1) | 28332 | 57509 | 70950 | 13441 | 1.23 | 0.23 | 136.0 | -1413 | 0.93 | -29.4 | 2281 | -22.7 | 0.71 |
| Barnyard + sesame (4:2) | 27822 | 56905 | 66913 | 10008 | 1.18 | 0.18 | 101.3 | -1805 | 0.89 | -46.0 | 2263 | -26.1 | 0.54 |
| Barnyard + sesame (3:3) | 27313 | 56301 | 62002 | 5701 | 1.10 | 0.10 | 58.3 | -1916 | 0.84 | -68.9 | 2258 | -17.9 | 0.31 |
| Barnyard + Sesame (2:4) | 26777 | 55643 | 59671 | 4028 | 1.07 | 0.07 | 43.0 | 216 | 0.84 | -72.4 | 2347 | -6.7 | 0.28 |
| Barnyard + Sesame (1:5) | 26267 | 55039 | 57539 | 2500 | 1.05 | 0.05 | 28.3 | 2553 | 0.83 | -82.4 | 2465 | 12.2 | 0.18 |
| CD (5%) | | | 8099 | 8099 | 0.14 | 0.15 | 114.2 | 3041 | 0.05 | 18.9 | 199 | 19.8 | 0.19 |
| SEm (±) | | | 2758 | 2758 | 0.05 | 0.05 | 38.9 | 1016 | 0.02 | 6.3 | 67 | 6.6 | 0.06 |

Variable Cost; TC, Total Cost; BCR, Benefit Cost Ratio; VCR, Value Lost Ratio; MAI, Monetary Advantage Index; RNRI, Relative Net Returns Index; REE, Relative Economics Efficiency

Barnyard millet intercrop with greengram recorded higher cost compared to barnyard millet + sesame intercropping at each row ratio. Decrement in rows of barnyard millet in comparison to intercrop from 5:1 to 1:5 declined the variable cost as well as total cost. All intercropping systems except barnyard millet + greengram (4:2 and 1:5) recorded fewer net returns compared to sole barnyard millet. Among all intercropping systems, significantly higher gross return (₹ 78,976 ha⁻¹) was recorded with barnyard millet + greengram (1:5). Among all intercropping systems, barnyard millet + greengram (1:5) closely followed by barnyard millet + greengram (4:2) recorded significantly higher net return (₹ 23,111 ha⁻¹) (Table 3), which was 15.3% higher over sole barnyard millet crop. All intercropping systems except barnyard millet + greengram (4:2 and 1:5) recorded lower benefit: cost (BCR), value cost ratio (VCR) and per day return over sole barnyard millet crop. Barnyard millet + greengram (1:5) closely followed by barnyard millet + greengram (4:2) recorded significantly higher BCR (1.42), VCR (0.42) and per day return (₹ 300.3 ha⁻¹ day⁻¹), which were 6.0, 23.5 and 15.5% higher over sole barnyard millet crop. Similar results were also reported by Chaudhary (2012) and Kumar *et al.*, (2023).

Thus, the study concluded that sesame intercropping in barnyard millet was uneconomical over sole barnyard millet. Considering all intercropping indices calculated to assess the relative competitiveness, advantage and efficiency of different intercropping systems, Barnyard millet + greengram (1:5) closely followed by barnyard millet + greengram (4:2) was found most economical and suitable system with higher Land Equivalent Ratio (1.25), Barnyard millet Equivalent Yield (2977 kg/ha), Land Use Efficiency (119.4), Area Time Equivalent Ratio (1.14), Relative Crowding Coefficient (1.79), Monetary advantage Index (₹ 10,756/ha), System Productivity Index (-2903), Intercropping Advantage Index (34.6), Net Return (₹ 23,111 ha⁻¹), Benefit Cost Ratio (1.42) and per day return (₹ 300.3). Hence, barnyard millet intercrop greengram in row ratio of 1:5 and 4:2 is a viable option for higher productivity and profitability of millet growers in a sustainable way.

REFERENCES

- Adetiloye, P.O., Ezedima, F.O.C. and Okigbo, B.N. 1983. A land equivalent coefficient concept for the evaluation of competitive and productive interactions in simple to complex crop mixtures. *Ecological Modelling* **19**: 27–39.
- Ahlawat, I.P.S. and Gangaiah, B. 2010. Effect of land configuration and irrigation on sole and linseed (*Linum usitatissimum*) intercropped chickpea (*Cicer arietinum*). *The Indian Journal of Agricultural Sciences* **80**(3): 250–53
- Ajibola, A.T. and Kolawole, G.O. 2019. Agronomic evaluation of performance of sesame varieties in maize-based intercropping system in the southern Guinean savanna of Nigeria.

- Journal of Experimental Agriculture International* **37**(3): 1–10.
- Anishetra, S. and Kalaghatagi, S.B. 2020. Evaluation of Sesame (*Sesamum indicum* L.) based intercropping systems with millets by varying row proportions under dry condition. *Indian Journal of Agricultural Research* **55**(4): 501–504.
- Avasthe, R.K., Devi, S.H., Bhupenchandra, I., Kumar, A., Chongtham, S.K., Babu, S., Singh, R., Das, A., Gudade, B.A. and Bora, S.S. 2023. Agro-tactics for reducing carbon footprint in agricultural production systems: A review. *Indian Journal of Agronomy* **68**(2): 115–125. <https://doi.org/10.59797/ija.v68i2.332>
- Azam-Ali, S.N. and Squire, G.R. 2002. Principles of Tropical Agronomy. Wallingford, UK, CABI.
- Baldev, R., Chaudhary, G.R., Jat, A.S. and Jat, M.L. 2003. Effect of integrated weed management and intercropping systems on growth and yield of pear millet (*Pennisetum glaucum*). *Indian Journal of Agronomy* **48**(4): 254–258.
- Banik, P. 1996. Evaluation of wheat (*T. aestivum*) and legume intercropping under 1:1 and 2:1 row-replacement series system. *Journal of Agronomy and Crop Science* **176**: 289–294.
- Banik, P., Midya, A., Sarkar, B.K. and Ghose, S.S. 2006. Wheat and chickpea intercropping systems in an additive series experiment, advantages and weed smothering. *European Journal of Agriculture* **24**: 325–332.
- Banik, P., Sasmal, T., Ghosal, P.K. and Bagechi, D.K. 2000. Evaluation of mustard (*Brassica campestris* var. *Toria*) and legume intercropping under 1:1 and 2:1 row-replacement series systems. *Journal of Agronomy and Crop science* **185**: 9–14.
- Bantie, Y., Fetien, A. and Tadesse, D. 2014. Competition indices of intercropped lupine(local) and small cereals in additive series in West Gojjam, North Western Ethiopia. *American Journal of Plant Science* **5**: 1,296–1,305.
- Buttar, T.S., Sharma, V. and Bharat, R. 2023. Effect of tillage practices, mulching and intercropping on rainfed maize (*Zea mays*) in foothill of Shivaliks, Jammu, Jammu and Kashmir. *Indian Journal of Agronomy* **68**(2): 171–175 <https://doi.org/10.59797/ija.v68i2.350>
- Chapke, R.R., Shyam Prasad, G., Das, I.K., Hari Prasanna, K., Singode, A., Kanthi Sri, B.S. and Tonapi, V.A. 2020. Latest millet production and processing technologies. Booklet, ICAR-Indian Institute of Millets Research, Hyderabad, India: pp82.
- Choudhary, R., Dodia, I.N., Choudhary, R. and Golada, S.L. 2012. Effect of pear millet-based pulses intercropping in rained conditions. *International Journal of Forestry and Crop Improvement* **3**(2): 112–115.
- Dass, A. and Sudhishri, S. 2010. Intercropping in finger millet (*Eleusine coracana*) with pulses for enhanced productivity, resource conservation and soil fertility in uplands of Southern Orissa. *Indian Journal of Agronomy* **55**(2): 89–94.
- Dhaka, A.K., Pannu, R.K., Kumar, S., Malik, K. and Singh, B. 2015. Biological feasibility, economic viability and energy efficiency of intercropping fodder sorghum (*Sorghum bicolor*) in seed crop of dhaincha (*Sesbania aculeata*). *Indian Journal of Agricultural Sciences* **85**(1): 20–27.
- Dhaka, A.K., Jat, R.D., Singh, B., Dhaka, P., Kumar, S. and Kumar, S. 2023b. Relative yield, competition, land use and economic performance of chickpea-based intercropping systems. *Legume Research* **51**(41): 1–8.
- Dhaka, B.K., Dhaka, P., Singh, B., Kamal, A. and Dhaka, A.K. 2023a. Intercropping options for sustainable minor millet production: A Review. *International Journal of Environment and Climate Change* **13**(12): 89–100.
- Dhima, K.V., Lithougidis, A.S., Vasilakoglou, I.B. and Dordas, C.A. 2007. Competition indices of common vetch and cereal intercrop in two seedling ratios. *Field Crop Research* **100**: 249–256.
- Ehrmann, J. and Ritz, K. 2014. Plant: soil interactions in temperate multi-cropping production systems. *Plant Soil* **376**: 1–29.
- Esmaceli, A., Sadeghpour, A., Hosseini, S.M.B., Jahanzad, E., Chaichi, M.R. and Hashemi, M. 2011. Evaluation of seed yield and competition indices for intercropped barley (*Hordeum vulgare*) and annual medic (*Medicago scutellata*). *International Journal of Plant Production* **4**: 395–404.
- FAO 2022. Food and Agriculture Organization of the United Nations. FAOSTAT.
- Fung, K.M., Tai, A.P.K., Yong, T., Liu, X. and Lam, H. 2019. Co-benefits of intercropping as a sustainable farming method for safeguarding both food security and air quality. *Environmental Research Letter* **14**(4): p.044011.
- Gomez, K.A. and Gomez, A.A. 1984. Statistical procedures for agricultural research 2nd edn, 180–209.
- Gupta, K.C., Kumar, V., Praharaj, S. and Yadav, M.R. 2019. Productivity and profitability of chickpea+ linseed intercropping system as influenced by spatial arrangement of crops in Semi-arid Eastern Plain Zone of Rajasthan. *Journal of crop and weed* **15**(2): 110–114.
- Habib, M.K., Dhaka, A.K., Singh, B., Kumar, S. and Bhatia, J.K. 2016. Economic and land use evaluation of barley based intercropping systems. *Indian Journal of Economics and Development* **12**(4): 793–798.
- Harris, D., Natarajan, M. and Willey, R.W. 1987. Physiological basis for yield advantage in a sorghum/groundnut intercrop exposed to drought. Dry-matter production, yield, and light interception. *Field Crops Research* **17**(3-4): 259–272.
- Hatfield, J.L. and Karlen, D.L. 1993. Sustainable agriculture systems. Publisher: CRC Press.
- IIMR 2018. Annual Report 2017-18, Hyderabad: Indian Institute of Millet Research.
- Jain, T.C. and Rao, G.M. 1980. Note on a new approach analysis of yield data in intercropping system. *Indian Journal of Agricultural science* **50**(12): 970–972.
- Jakhar, P., Adhikary, P.P., Naik, B.S. and Madhu, M. 2015. Finger millet-groundnut strip cropping for enhanced productivity and resource conservation in upland of Eastern Ghats of Odisha. *Indian Journal of Agronomy* **60**: 365–371.
- Kiwia, A., Kimani, D., Harawa, R., Jama, B. and Sileshi, G. 2019. Sustainable Intensification with Cereal-Legume Intercropping in Eastern and Southern Africa. *Sustainability* **11**(10): 2,891.
- Kumar, N., Ahamad, A., Kumar, R., Singh, A.K., Prasad, S., Baheliya, A.K. and Yadav G. 2022. Productivity and profitability of pigeonpea (*Cajanus cajan*)-based intercropping systems under diverse nutrient management practices in rainfed condition. *Journal of Agronomy* **67**(4): 431–436. <https://doi.org/10.59797/ija.v67i4.150>
- Kumar, P., Jyothi Lakshmi, N., Dube, S.D., Mani, V.P. 2000. Genotypic difference in photosynthesis and its associated parameters in relation to yield among Barnyard Millet (*Echinochloa frumentacea*) genotypes under condition in

- hills. *Indian Journal of Agricultural Science* **70**(6): 374–377.
- Kumar, S., Shukla, A.K. and Singh, H.V. 2013. Intercropping of pearl millet+ cowpea as rainfed fodder crops with aonla based agri-horti-system. *International Journal of Horticulture* **3**(7): 28–34.
- Maitra Sagar 2020. Intercropping of small millets for agricultural sustainability in drylands: A review. *Crop Research* **55**(3 & 4): 162–171.
- Maitra, S., Ghosh, D.C., Sundra, G. and Jana, P.K. 2001. Performance of intercropping legumes in finger millet at varying fertility levels. *Indian Journal of Agronomy* **46**(1): 38–44.
- Manjunath, M., Vajjaramatti and Kalaghatagi, S.B. 2018. Performance of pigeonpea and millets in intercropping systems under rainfed conditions. *Journal of Farm Sciences* **31**: 199–01.
- Mekuanint, T. 2020. Competition indices and monetary advantage index of intercropping maize (*Zea mays* L.) with legumes under supplementary irrigation in Tselemti District, Northern Ethiopia. *Journal of Cereals and Oilseeds* **11**(1): 30–36.
- Odo, P.E. 1991. Evaluating short and tall sorghum varieties in mixtures with cowpea in Sudan Savanna of Nigeria: LER, grain yield and system productivity index. *Experimental Agriculture* **27**(4): 435–441.
- Padhi, A.K., Panigrahi, R.K. and Jena, B.K. 2010. Effect of planting geometry and duration of intercrops on performance of pigeonpea-finger millet intercropping systems. *Indian Journal of Agricultural Research* **44**(1): 43–47.
- Pal, M., Singh, K.M. and Ahlawat, I.P.S. 1985. Cropping system research: Concept, needs and directions. Indian Society of Agronomy. National symposium, CSSRI, Karnal, pp.1–45.
- Poddar, R., Kundu, R. and Kumar, S. 2017. Assessment of chickpea-spices intercropping productivity using competitive indices under irrigated conditions of Haryana. *Agricultural Research* **6**(3): 241–247.
- Prajwal, N. and Kalaghatagi, S.B. 2018. Studies on castor (*Ricinus communis* L.) based millets intercropping systems under rainfed condition. *Journal of Farm Sciences* **31**(4): 381–383.
- Ram, K. and Meena, R.S. 2014. Evaluation of pearl millet and mungbean intercropping systems in Arid Region of Rajasthan (India). *Bangladesh Journal of Botany* **43**(3): 367–370.
- Renganathan, V.G., Vanniarajan, C., Karthikeyan, A. and Ramalingam, J. 2020. Barnyard millet for food and nutritional security: Current status and future research direction. *Frontier in Genetics*. **23**(11): 500.
- Sharmili, K., Parasuraman, P. and Sivagamy, K. 2023. Effect of inter and sequential cropping of pulses in little millet (*Panicum sumatranse* L.) based cropping system. *Indian Journal of Agricultural Research* **57**(1): 52–55.
- Singh, B., Singh, A.P. Gupta, V., Abrol, V., Kumar, J., Singh, P., Kumar, V. and Raina, S. 2022. Influence of nutrient-management practices on crop-growth indices, soil fertility and yield of pearl millet (*Pennisetum glaucum*)–gobhi sarson (*Brassica napus* subspecies napus) cropping system under north-west Himalayan region. *Indian Journal of Agronomy* **67**(3): 221–226. <https://doi.org/10.59797/ija.v67i3.26>
- Willey, R.W. 1979. Intercropping, its importance and research needs. Part-I. Competition and yield advantages. *Field Crop Abstract* **32**(1): 1–10.
- Yayeh, B.B., Abay, F. and Dessalegn, T. 2014. Effect of lupine (*Lupinus spp.*) intercropping and seed proportion on the yield and yield component of small cereals in North western Ethiopia. *African Journal of Agricultural Research* **9**(30): 2,287–2,297.

Herbicidal weed management options for pigeonpea (*Cajanus Cajan*) grown in southeastern Rajasthan

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ABSTRACT

A field experiment was carried out during the *kharif* seasons of 2020–21, 2021–22 and 2022–23 at Kota, Rajasthan, to study the effect of post-emergence herbicides on productivity of pigeonpea [*Cajanus cajan* (L.) Millsp]. The results indicated that the minimum weed density and dry weight, and the highest yield attributes, yields, and net return of pigeonpea were obtained under weed free plot. All the herbicidal treatments significantly reduced the weed density and biomass compared to the weedy check. However, application of pendimethalin 30 EC @ 0.75 kg /ha (PE) fb Imazethapyr 10 SL @ 100 g/ha at 20–25 DAS + one inter-cultivation at 50 DAS recorded significantly higher plant height (1.82 m), pods/branch (22.96), pods/plant (206.3), weed control efficiency (84.39% at 60 DAS), grain yield (1,868 kg/ha), net return (₹ 87.66 × 10³/ha) and B: C ratio (3.35) over weedy check. This leads to the 61.73% higher pigeonpea grain yield over the weedy check plot. Hence it can be inferred that the application of pendimethalin 30 EC @ 0.75 kg /ha (PE) fb Imazethapyr 10 SL @ 100 g/ha at 20–25 DAS + one inter-cultivation at 50 DAS is an efficient weed control method for profitable cultivation of pigeonpea in south eastern Rajasthan.

Key words: Net returns, Pigeonpea, Weed-management, Weed-control efficiency, Yield

Pigeonpea [*Cajanus cajan* (L.) Millsp] is one of the major grain legumes of the tropical and subtropical regions. India accounts for 90% of the global pigeonpea area and 85% of production. Owing to the nature of growth, pigeonpea is considered a climate-resilient pulse crop in rainfed conditions. Biotic and abiotic stresses, non-availability of suitable varieties, and inadequate transfer of technology are the major factors for the reduction of crop yield (Kumar *et al.*, 2023). Among these production constraints, heavy infestation of weeds is one of the major concerns, especially at early stage of crop growth, when crop has slow growth rate, and rapid and vigorous growth of weeds due to enough soil moisture, wider spacing, and favorable climatic condition after sowing of crops which results in heavy drain of available nutrients and moisture often smoother the tender crop and reduce the yield (Shekhawat *et al.*, 2022). Competitive stress of weeds causes a reduction in the grain yield of pigeonpea up to 80% (Padmaja *et al.*, 2013). As pigeonpea is usually grown during the rainy season, when the manual method of weed control is

difficult to imply therefore, the chemical method of weed control is a more feasible, less laborious, cost-effective, and economical option. Weeds, compete with pigeonpea for nutrients and other resources and thus the yield is decreased (Bidlack *et al.*, 2006). Weed management strategies attempt to limit the deleterious effects of weeds on crop plants. In pigeonpea, the initial 6-8 weeks period is the critical period of the crop-weed competition. Effective and economical weed control may be possible through chemical means due to the unavailability of human labor at critical periods of competition and its high cost coupled with heavy and continuous rainfall in *kharif* season. Herbicide and its integration with manual and mechanical methods can prove more effective and economical (Nimbargi *et al.*, 2021). The use of integrated weed management methods would make weed control more acceptable to farmers. Therefore, the present investigation was conducted to find suitable and economical weed control methods for enhancing the productivity and profitability of pigeonpea.

MATERIALS AND METHODS

The field experiment was conducted during the *Kharif* seasons of 2020–21, 2021–22 and 2022–23 at Agricultural Research Station, Kota (26° North latitude, 76°-6' East longitude and 260 m above mean sea level), Rajasthan. The

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study area falls under the humid south eastern plain zone of Rajasthan. The soil of the experimental field was vertisol having bulk density 1.50 Mg/m³, pH 7.76, CEC 35 Cmol/kg, medium in organic carbon 5.4 g/kg, available N (281 kg/ha), available P (22.7 kg/ha) and high in available K (316 kg/ha). The total rainfall received during the crop season of 2020–21, 2021–22, and 2022–23 was 499.2 mm, 1370 mm, and 1119.6 mm, respectively.

The experiment was laid out in randomized block design with three replications. Treatments comprised viz; T₁, weed free; T₂, weedy check; T₃, 2 hand weeding at 20 and 40 DAS/ Inter cultivation; T₄, pendimethalin 30 EC @ 0.75 kg/ha (PE) followed by (fb) imazethapyr 10 SL @ 100 g/ha at 20–25 DAS + inter cultivation at 50 DAS; T₅, pendimethalin 30 EC @ 0.75 kg/ha (PE) fb chlorimuron ethyl 25 WP @ 9 g/ha at 20–25 DAS + inter cultivation at 50 DAS; T₆, pendimethalin 30 EC @ 0.75 kg/ha (PE) fb fenoxaprop ethyl 9.3 EC @ 70 g/ha at 20–25 DAS + inter cultivation at 50 DAS; T₇, pendimethalin 30 EC @ 0.75 kg/ha (PE) fb propaquizalop 2.5% + imazethapyr 3.7% w/w @ 50 + 75 = 125 g/ha at 20–25 DAS + inter cultivation at 50 DAS; T₈, pendimethalin 30 EC @ 0.75 kg/ha (PE) fb sodium acifluorfen 16.5% + clodinafop propargyl 8% @ 245 g/ha at 20–25 DAS + inter cultivation at 50 DAS; T₉, pendimethalin 30 EC @ 0.75 kg/ha (PE) fb chlorimuron ethyl 9 g + quizalofop ethyl 50 g/ha at 20–25 DAS + inter cultivation at 50 DAS; T₁₀, pendimethalin 30 EC @ 0.75 kg/ha (PE) fb chlorimuron ethyl 6 g + quizalofop ethyl 37.5 g/ha at 20–25 DAS + inter cultivation at 50 DAS; T₁₁, pendimethalin 30 EC @ 0.75 kg/ha (PE) fb chlorimuron ethyl 9 g + fenoxaprop ethyl 70 g/ha at 20–25 DAS + inter cultivation at 50 DAS; T₁₂, pendimethalin 30 EC @ 0.75 kg/ha (PE) fb chlorimuron ethyl 6 g + fenoxaprop ethyl 50 g/ha at 20–25 DAS + inter cultivation at 50 DAS and T₁₃, pendimethalin 30 EC @ 0.75 kg/ha (PE) fb imazethapyr + imazamox @ 100 g/ha at 20–25 DAS + inter cultivation at 50 DAS.

Pigeonpea variety ICPL 88039 was sown with the seed rate of 18 kg/ha at the spacing of 60 cm x 20 cm. The seeds were sown in the first fortnight of July during experimentation. Basal application of 20 kg N and 50 kg/ha P₂O₅ were applied through diammonium phosphate and urea for the requirement of nitrogen and phosphorus. A common basal dose of zinc sulfate (21% Zn) @ 25 kg/ha was applied uniformly to all the plots. The required quantity of herbicide as per treatment was applied with manually operated knapsack sprayer using a spray volume of 500 L/ha. Weed density (number/m²) and weed dry weight (g/m²) were measured from the randomly selected samples at 2 places in each plot with the help of 0.25 m² quadrat at 30 and 60 days after sowing. Weed control efficiency (WCE) was also calculated based on the dry-matter production of

weeds. Data on weed count and weed biomass were subjected to square root transformation to reduce larger variation in original value by using the formula [$\sqrt{(x + 0.5)}$] before carrying out analysis of variance, and comparison among treatments were made on transformed values only.

The crop was harvested on 25 December 2020, 15 February 2022, and 20 January 2023. Yield-attributing traits and seed yields were recorded at the time of harvesting. The economic analysis of each treatment was done based on prevailing market prices of the inputs used and outputs obtained under each treatment. The data obtained on various observations were tabulated and statistically analyzed by using the analysis of variance (ANOVA) and the significance of the treatments was tested by F test. Critical difference (CD) at 5% level of significance was determined for each character to compare the differences among treatment means (Gomez and Gomez, 1984).

RESULTS AND DISCUSSION

Effect on weeds

The weed flora in the experimental field consisted of a mixed population viz. *Echinochloa crus-galli* (L.) Beauv., *Echinochloa colonum* (L.) Link and *Cynodon dactylon* among grassy weeds and *Eclipta alba* (L.) Hoesk., *Commelina benghalensis* L., *Amaranthus viridis* (L.), *Trianthema benghalensis* L., *Celosia argentea*, *Capsularia arvensis* L., *Phyllanthus niruri*, *Corchorus olitorius*, *Alternanthera caracasana* among the broad leaf weeds and sedges, *Cyperus rotundus* and *Cyperus iria* (L.). Analysis of the spectrum of weed flora revealed that grassy weeds are more problematic, constituting 60%, followed by sedges (25%) and broad leaf weeds (15%) among the weed population. The weedy check recorded significantly higher weed population and weed dry weight at 30 and 60 DAS than any other treatment (Table 1). All the weed control measures resulted in lower weed density and weed dry weight at 30 DAS and 60 DAS than the weedy check. However, minimum weed count at 30 and 60 DAS was observed in 2 HW at 20 & 40 DAS. Among herbicidal treatments, application of pendimethalin 30 EC @ 0.75 kg/ha (PE) fb Imazethapyr 10 SL @ 100 g/ha at 20–25 DAS + One inter cultivation at 50 DAS, pendimethalin 30 EC @ 0.75 kg/ha (PE) fb propaquizalop 2.5% + Imazethapyr 3.7% w/w @ 50+75 = 125 g/ha at 20–25 DAS + One inter cultivation at 50 DAS and pendimethalin 30 EC @ 0.75 kg/ha (PE) fb Imazethapyr + Imazamox @ 100 g/ha at 20–25 DAS + One inter cultivation at 50 DAS recorded significantly lower weed density and weed dry weight at 30 and 60 DAS as compared to other herbicidal treatments being statistically at par with each other about weed density and weed dry weight at both the stages.

Maximum weed control efficiency was observed at 30

Table 1. Effect of weed management on weed count, dry weight of weeds, and weed control efficiency in pigeonpea (pooled data of 3 years)

| Treatment | Weed count (No./m ²) | | Weed dry weight (g/m ²) | | Weed control efficiency (%) | |
|---|-------------------------------------|-------------------|--|-------------------|--------------------------------|--------|
| | 30 DAS | 60 DAS | 30 DAS | 60 DAS | 30 DAS | 60 DAS |
| T ₁ , Weed free | 0.00 | 0.00 | 0.00 | 0.00 | 100.00 | 100.00 |
| T ₂ , Weedy check | 11.4 (130.2) * | 13.6 (185.6) * | 5.14 (25.89) * | 7.95 (63.28) * | 0.00 | 0.00 |
| T ₃ , 2 Hand Weeding at 20 and 40 DAS/ Inter cultivation | 2.20 (4.86) | 4.45 (19.81) | 1.70 (2.42) | 3.49 (12.19) | 90.60 | 80.94 |
| T ₄ , Pendimethalin 30 EC @ 0.75 kg ai/ha (PE) followed by Imazethapyr 10 SL @ 100 g ai/ha at 20–25 DAS, fb + 1 Inter cultivation at 50 DAS. | 5.49 (30.2) | 7.13 (50.94) | 2.90 (7.89) | 3.13 (9.81) | 69.46 | 84.39 |
| T ₅ , Chlorimuron ethyl 25 WP @ 9 g ai/ha at 20–25 DAS | 6.38 (40.7) | 8.48 (72.06) | 3.04 (8.73) | 4.04 (16.31) | 66.05 | 74.13 |
| T ₆ , Fenoxaprop ethyl 9.3 EC @ 70 g ai/ha at 20–25 DAS | 6.93 (48.1) | 8.01 (64.30) | 3.11 (9.17) | 3.80 (14.46) | 64.44 | 77.14 |
| T ₇ , Propaquizalop 2.5% + Imazethapyr 3.7% w/w @ 50+75 = 125 g ai/ha at 20–25 DAS | 5.31 (28.2) | 7.63 (58.26) | 3.02 (8.63) | 3.48 (12.10) | 66.52 | 80.90 |
| T ₈ , Sodium Acifluorfen 16.5% +Clodinafop propargyl 8% @ 245 g ai/ha at 20–25 DAS | 5.06 (25.7) | 5.88 (34.64) | 2.67 (6.62) | 3.08 (9.50) | 74.27 | 85.02 |
| T ₉ , Chlorimuron ethyl 9 g + quizalofop ethyl 50 g ai/ha at 20–25 DAS | 4.94 (24.5) | 6.51 (42.50) | 2.87 (7.74) | 3.64 (13.23) | 69.93 | 79.23 |
| T ₁₀ , Chlorimuron ethyl 6 g + quizalofop ethyl 37.5 g ai/ha at 20–25 DAS | 6.57 (43.2) | 9.01 (81.35) | 3.06 (8.86) | 4.27 (18.20) | 65.72 | 71.22 |
| T ₁₁ , Chlorimuron ethyl 9 g + Fenoxaprop ethyl 70 g ai/ha at 20–25 DAS | 6.26 (39.2) | 7.84 (61.48) | 2.96 (8.24) | 3.74 (13.99) | 67.90 | 78.00 |
| T ₁₂ , Chlorimuron ethyl 6 g + Fenoxaprop ethyl 50 g ai/ha at 20–25 DAS | 6.71 (45.1) | 8.88 (78.99) | 3.00 (8.53) | 4.05 (16.42) | 66.80 | 74.06 |
| T ₁₃ , Imazethapyr + Imazamox @ 100 g ai/ha at 20–25 DAS | 5.48 (30.1) | 5.60 (57.76) | 2.95 (8.19) | 3.39 (11.46) | 68.25 | 81.82 |
| SEm± | 1.39 | 1.63 | 0.49 | 0.90 | 1.59 | 1.11 |
| CD (P=0.05) | 2.34 | 2.74 | 1.39 | 2.55 | 4.48 | 3.14 |

Note: Pendimethalin 30 EC @ 0.75 kg ai/ha as pre-emergent herbicide followed by one inter-cultivation at 50 DAS is common from T₄ to T₁₃.
*Data in parentheses indicate the original value of weeds and outside square root transformed values (sq. root of x + 0.5)

DAS under two-hand weeding at 20 and 40 DAS. However, application of pendimethalin 30 EC @ 0.75 kg/ha (PE) followed by (fb) sodium acifluorfen 16.5% + clodinafop propargyl 8% @ 245 g/ha at 20–25 DAS + inter cultivation at 50 DAS gave significantly higher weed control efficiency at 60 DAS as compared to weedy check being on par with application of pendimethalin 30 EC @ 0.75 kg a.i./ha (PE) fb Imazethapyr 10 SL @ 100 g a.i./ha at 20–25 DAS + One inter cultivation at 50 DAS. The lower intensity of weeds at all the stages with these two treatments having the application of pre, and post-emergence herbicides may be due to readily absorbed through

the roots and foliage, translocated in the xylem and phloem, and accumulated in growing points. It kills the weeds by inhibition of acetohydroxy acid. Results are in close conformity with the research findings of Padmaja *et al.*, (2013).

Effect on crop

Growth and yield attributes

All the weed control measures significantly increased growth and yield attributes as compared to the weedy check (Table 2). Maximum plant height (2.06 m), branches/plant (10.94), pods/branch (24.22), pods/plant

(244.4), seeds/pod, and 100 seed weight were observed in weed-free plots. Among chemical weed control measures, maximum plant height was recorded with the application of pendimethalin 30 EC @ 0.75 kg a.i./ha (PE) fb Imazethapyr + Imazamox @ 100 g/ha at 20–25 DAS + One inter cultivation at 50 DAS followed by application of pendimethalin 30 EC @ 0.75 kg/ha (PE) fb Imazethapyr 10 SL @ 100 g/ha at 20–25 DAS + One inter cultivation at 50 DAS. However, among herbicidal treatments, maximum number of branches per plant were obtained with application of pendimethalin 30 EC @ 0.75 kg/ha (PE) fb Imazethapyr + Imazamox @ 100 g/ha at 20–25 DAS + One inter cultivation at 50 DAS followed by application of pendimethalin 30 EC @ 0.75 kg/ha (PE) fb Propaquizalop 2.5% + Imazethapyr 3.7% w/w @ 50+75 = 125 g/ha at 20–25 DAS + One inter cultivation at 50 DAS. Pods/branch (22.96), pods/plant (206.3), seeds/pod (3.71) and 100 seed weight increased significantly with the pre-emergence application of pendimethalin 30 EC @ 0.75 kg/ha fb Imazethapyr 10 SL @ 100 g/ha at 20–25 DAS + One inter

cultivation at 50 DAS being statistically on par with pendimethalin 30 EC @ 0.75 kg/ha (PE) fb Propaquizalop 2.5% + Imazethapyr 3.7% w/w @ 50+75=125 g/ha at 20–25 DAS + One inter cultivation at 50 DAS and pendimethalin 30 EC @ 0.75 kg/ha (PE) fb Imazethapyr + Imazamox @ 100 g/ha at 20–25 DAS + One inter cultivation at 50 DAS over weedy check and other treatments. This might be owing to a significant reduction in weed density and weed dry weight. Effective control of weeds with pre and post-emergence application of herbicides might have resulted in increased growth and yield attributes of the crop, which reduces water and nutrient uptake by weeds (Shekhawat *et al.*, 2022; Singh *et al.*, 2023). Severe infestation of weed decreases the growth and yield attributes in weedy check. These results are similar to the findings of Nimbargi *et al.* (2021).

Yield

Different weed management practices had a significant influence on the seed yield, stalk, and biological yield of

Table 2. Effect of weed management on growth and yield attributes of pigeonpea (pooled data of 3 years)

| Treatment | Plant height (m) | Branches/plant | Pods/branch | Pods/plant | Seeds/pod | 100 seed weight (g) |
|---|------------------|----------------|-------------|------------|-----------|---------------------|
| T ₁ , Weed free | 2.06 | 10.94 | 24.22 | 244.4 | 3.95 | 9.44 |
| T ₂ , Weedy check | 1.37 | 7.93 | 13.01 | 102.4 | 3.05 | 8.49 |
| T ₃ , 2 Hand Weeding at 20 and 40 DAS/ Inter cultivation | 1.95 | 9.35 | 20.91 | 196.8 | 3.65 | 9.23 |
| T ₄ , Pendimethalin 30 EC @ 0.75 kg ai/ha (PE) followed by Imazethapyr 10 SL @ 100 g ai/ha at 20–25 DAS fb + 1 Inter cultivation at 50 DAS. | 1.82 | 9.19 | 22.96 | 206.3 | 3.71 | 9.23 |
| T ₅ , Chlorimuron ethyl 25 WP @ 9 g ai/ha at 20–25 DAS | 1.74 | 9.06 | 20.08 | 181.6 | 3.53 | 8.82 |
| T ₆ , Fenoxaprop ethyl 9.3 EC @ 70 g ai/ha at 20–25 DAS | 1.78 | 8.71 | 21.54 | 186.2 | 3.42 | 8.67 |
| T ₇ , Propaquizalop 2.5% + Imazethapyr 3.7 % w/w @ 50+75 = 125 g ai/ha at 20–25 DAS | 1.79 | 10.12 | 22.00 | 207.6 | 3.80 | 9.19 |
| T ₈ , Sodium Acifluorfen 16.5% + Clodinafop propargyl 8% @ 245 g ai/ha at 20–25 DAS | 1.80 | 9.52 | 19.07 | 181.3 | 3.42 | 8.77 |
| T ₉ , Chlorimuron ethyl 9 g + quizalofop ethyl 50 g ai/ha at 20–25 DAS | 1.79 | 9.34 | 19.60 | 183.0 | 3.46 | 8.83 |
| T ₁₀ , Chlorimuron ethyl 6 g + quizalofop ethyl 37.5 g ai/ha at 20–25 DAS | 1.69 | 9.03 | 20.24 | 182.5 | 3.41 | 8.72 |
| T ₁₁ , Chlorimuron ethyl 9 g + Fenoxaprop ethyl 70 g ai/ha at 20–25 DAS | 1.80 | 9.42 | 18.63 | 175.6 | 3.43 | 8.77 |
| T ₁₂ , Chlorimuron ethyl 6 g + Fenoxaprop ethyl 50 g ai/ha at 20–25 DAS | 1.72 | 9.51 | 19.09 | 181.8 | 3.36 | 8.63 |
| T ₁₃ , Imazethapyr + Imazamox @ 100 g ai/ha at 20–25 DAS | 1.90 | 10.02 | 21.57 | 205.7 | 3.67 | 8.86 |
| SEm± | 0.05 | 0.34 | 0.71 | 8.46 | 0.13 | 0.13 |
| CD (P=0.05) | 0.15 | 0.95 | 2.01 | 23.88 | 0.35 | 0.37 |

Note: Pendimethalin 30 EC @ 0.75 kg ai/ha as pre-emergent herbicide followed by one inter-cultivation at 50 DAS is common from T₄ to T₁₃.

pigeonpea crop (Table 3). The highest grain (2,116 kg/ha), stalk, and biological yield were recorded with weed-free plots. Among chemical weed control measures, grain yield (1,916 kg/ha), stalk, and biological yield of pigeonpea crop were found significantly superior with the application of pendimethalin 30 EC @ 0.75 kg/ha (PE) fb Propaquizalop 2.5% + Imazethapyr 3.7% w/w @ 50+75 = 125 g/ha at 20–25 DAS + One inter cultivation at 50 DAS, which remained on par with that of pendimethalin 30 EC @ 0.75 kg/ha (PE) (fb) Imazethapyr 10 SL @ 100 g/ha at 20–25 DAS + One inter cultivation at 50 DAS and pendimethalin 30 EC @ 0.75 kg/ha (PE) fb Imazethapyr + Imazamox @ 100 g/ha at 20–25 DAS + One inter cultivation at 50 DAS as compared to unweeded control having lowest yields. Weed management practices did not influence the harvest index. The increase in grain, stalk, and biological yield by the application of pendimethalin 30 EC @ 0.75 kg/ha (PE) fb Propaquizalop 2.5% + Imazethapyr 3.7% w/w @ 50+75 = 125 g/ha at 20–25 DAS + One inter cultivation at 50

DAS were owing to reduced weed density, weed dry weight and higher weed control efficiency resulted in higher pods/plant (Table 1). The minimum yields in unweeded checks were the results of severe weed competition. This could be attributed to the effective control of weeds during critical periods of crop weed competition which in turn reduced biotic stress (due to weed competition) and thus, provided weed-free environment for better growth and yield. These results are in close conformity with the finding of Patel *et al.*, (2024)

Economics

Economic data (Table 3) revealed that weed-free treatment gave the highest net realization of ₹ 98.26 x10³/ha. However, among all herbicidal treatments, application of pendimethalin 30 EC @ 0.75 kg/ha (PE) fb Imazethapyr 10 SL @ 100 g/ha at 20–25 DAS + One inter cultivation at 50 DAS gave highest net return (87.66 x 10³/ha) and benefit-cost ratio (3.35) being on par with pendimethalin

Table 3. Effect of weed management on yield, HI, and economics of pigeonpea (pooled data of 3 years)

| Treatment | Seed yield (kg/ha) | Stalk yield (kg/ha) | Biological yield (kg/ha) | HI (%) | Net return (₹ x10 ³ /ha) | Benefit: cost ratio |
|--|--------------------|---------------------|--------------------------|--------|-------------------------------------|---------------------|
| T ₁ , Weed free | 2,116 | 4,777 | 6,892 | 31.09 | 98.26 | 2.65 |
| T ₂ , Weedy check | 1,155 | 2,581 | 3,735 | 31.23 | 45.38 | 1.89 |
| T ₃ , 2 Hand Weeding at 20 and 40 DAS/ Inter cultivation | 1,794 | 4,381 | 6,175 | 29.04 | 76.61 | 2.34 |
| T ₄ , Pendimethalin 30 EC @ 0.75 kg ai/ha (PE) followed by Imazethapyr 10 SL @ 100 g ai/ha at 20–25 DAS fb + 1 Inter cultivation at 50 DAS. | 1,868 | 4,392 | 6,259 | 30.13 | 87.66 | 3.35 |
| T ₅ , Chlorimuron ethyl 25 WP @ 9 g ai/ha at 20–25 DAS | 1,539 | 3,566 | 5,105 | 30.68 | 63.15 | 2.12 |
| T ₆ , Fenoxaprop ethyl 9.3 EC @ 70 g ai/ha at 20–25 DAS | 1,593 | 3,719 | 5,312 | 30.60 | 65.53 | 2.11 |
| T ₇ , Propaquizalop 2.5% + Imazethapyr 3.7% w/w @ 50+75 = 125 g ai/ha at 20–25 DAS | 1,916 | 4,268 | 6,184 | 31.74 | 86.60 | 2.86 |
| T ₈ , Sodium Acifluorfen 16.5% + Clodinafop propargyl 8% @ 245 g ai/ha at 20–25 DAS | 1,644 | 3,713 | 5,357 | 31.22 | 68.99 | 2.28 |
| T ₉ , Chlorimuron ethyl 9 g + quizalofop ethyl 50 g ai/ha at 20–25 DAS | 1,558 | 3,495 | 5,053 | 31.55 | 63.63 | 2.08 |
| T ₁₀ , Chlorimuron ethyl 6 g + quizalofop ethyl 37.5 g ai/ha at 20–25 DAS | 1,584 | 3,624 | 5,209 | 31.08 | 65.61 | 2.16 |
| T ₁₁ , Chlorimuron ethyl 9 g + Fenoxaprop ethyl 70 g ai/ha at 20–25 DAS | 1,507 | 3,498 | 5,005 | 30.79 | 59.57 | 1.90 |
| T ₁₂ , Chlorimuron ethyl 6 g + Fenoxaprop ethyl 50 g ai/ha at 20–25 DAS | 1,540 | 3,541 | 5,081 | 30.92 | 62.20 | 2.02 |
| T ₁₃ , Imazethapyr + Imazamox @ 100 g ai/ha at 20-25 DAS | 1,770 | 4,187 | 5,956 | 30.46 | 77.09 | 2.59 |
| SEm± | 70.53 | 129.3 | 164.9 | 0.91 | 4.77 | 0.16 |
| CD (P=0.05) | 199.12 | 365 | 466 | NS | 13.46 | 0.45 |

Note: Pendimethalin 30 EC @ 0.75 kg ai/ha as pre-emergent herbicide followed by one Inter cultivation at 50 DAS is common from T₄ to T₁₃.

30 EC @ 0.75 kg/ha(PE) fb Propaquizalop 2.5% + Imazethapyr 3.7% w/w @ 50 +75 = 125 g/ha at 20–25 DAS + One inter cultivation at 50 DAS and pendimethalin 30 EC @ 0.75 kg/ha (PE) fb Imazethapyr + Imazamox @ 100 g/ha at 20–25 DAS + One inter cultivation at 50 DAS than weedy check and other weed control measures. The lower net return and B: C ratio in the weedy check was due to high infestation of weeds resulting in low weed control efficiency and yield. These results conform with those reported by Singh and Sekhon (2013); Yadav *et al.* (2013) and Singh *et al.* (2016).

Thus, it can be concluded that pre-emergence application of pendimethalin 30 EC @ 0.75 kg/ha fb post-emergence application of Imazethapyr 10 SL @ 100 g ha at 20–25 DAS + one inter-cultivation at 50 DAS is more productive and remunerative with effective weed control in pigeonpea.

REFERENCES

- Bidlack, J.E., Middick, A., Shantz, D., MacKown, C.T., Williams, R.D., Rao, S.C. 2006. Weed control in a pigeon pea–wheat cropping system. *Field Crops Research* **96**: 63–70. <https://doi.org/10.1016/j.fcr.2005.05.005>
- Gomez, K.A and Gomez, A.A. 1984. Statistical procedures for agricultural research. IRRI, Wiley-Inter Science pub. New York, USA, 680.
- Kumar, A., Avasthe, R., Singh, R., Babu, S., Das, S.K., Ravisankar, N., Panwar, A.S., A. Qureshi, A., Laha, R.G., Mishra, V.K., Bhupenchandra, I. and Prasad S.K. 2023. Productivity and profitability of maize (*Zea mays*) cultivars under organic management conditions in mid-hills of Sikkim. *Indian Journal of Agronomy* **68**(1): 26–29. <https://doi.org/10.59797/ija.v68i1.198>
- Nimbargi, Y.A., Mavarkar, N.S., Rathod, P.S., Ganpathi and Nandish, M.S. 2021. Influence of pre and post-emergence herbicides on weed dynamics, WCE, and yield of pigeonpea under rainfed conditions. *International Journal of Plant & Soil Science* **33**(19): 35–46.
- Padmaja, B., Reddy, M.M and Reddy, D.V.V. 2013. Weed control efficiency of pre-and post-emergence herbicides in pigeonpea (*Cajanus cajan* L). *Journal of Food Legumes* **26**: 44–45.
- Patel, A., Banjara, G.P. Shrivastava, G.K., Rathore, S.S., Shekhawat, K., Painkara, S.K., Lakra, A.K. and Mishra, R.K. 2024. Chemical weed management in chickpea (*Cicer arietinum*) under Vertisols of Eastern Plateau Plain zone of India. *Indian Journal of Agronomy* 166–171. DOI: 10.59797/ija.v69i2.5502
- Shekhawat, K., Rathore, S.S., Babu, S., Raj, R. and Chauhan, B.S. 2022. Exploring alternatives for assessing and improving herbicide use in intensive agroecosystems of South Asia: A review. *Advances in Weed Science* 40(spe1), e0202200116.
- Singh, D., Kushwaha, A. and Kushwaha, H.S. 2023. Effect of nutrient and pest management on productivity and profitability of pigeonpea (*Cajanus cajan*). *Indian Journal of Agronomy* **68**(2): 194–198: <https://doi.org/10.59797/ija.v68i2.354>
- Singh, G and Sekhon, H.S. 2013. Integrated weed management in pigeonpea [*Cajanus cajan* (L.)]. *World Journal of Agricultural Sciences* **9**: 86–91.
- Singh, G., Kaur, H.P and Khanna, V. 2016. Integration of pre-and post-emergence herbicides for weed management in pigeonpea. *Indian Journal of Weed Science* **48**(3): 336–338.
- Yadav, S.L., Kaushik, M.K., Dubey, R.K., Yadav, R.K. and Jat, A.L. 2013. Biological and economic feasibility of different weed control options in cluster bean [*Cyamopsis tetragonoloba* (L.) Taub.] in South West Rajasthan. *Indian Journal of Agricultural Sciences* **83**(8): 885–888.



Different nitrogen levels with nano and prilled urea spray on productivity and profitability of maize (*Zea mays*) in alfisols of Jharkhand

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ABSTRACT

A ground-breaking and enduring way to significantly reduce the use of conventional nitrogen fertilizer is to use nano-urea as a nitrogen supplement. The combination of nano and prilled urea was investigated in this study to address this issue and allow for a 25% reduction in the recommended urea dosage. Research on rainfed maize during *kharif* season 2022-23 was conducted at ICAR-IARI Jharkhand. Twelve different combinations of conventional prilled urea, nano and prilled urea spray were investigated in the study. In the fields, the experiment used a randomized block design. Different treatments included applying prilled urea as a 2% solution in 150 liters of water per hectare and nano-urea at a rate of 1250 ml/acre applied twice through foliar application. Results showed that applying two additional applications of nano-urea along with 75% of the recommended dose of prilled-urea was the most successful fertilization strategy. This performed statistically equal with both the 100% recommended dose and the 100% recommended dose with two prilled urea spray applications in terms of yield, and cost-to-benefit ratio. The study's findings show that nano-urea can potentially replace at least 25% of the dosage of prilled urea *i.e.* recommended, providing a more profitable and environmentally friendly method of cultivation.

Key words: B:C, Conventional urea, Maize, Nano-urea, Nitrogen and Productivity

In the world (comma) maize is cultivated on over 197 million hectares giving 1,137 million tonnes with 5.8 tonnes per hectare productivity (FAO Stat, 2021). In India, maize covers around 9.86 million hectares and produces 28.5 million tones with 2.89 t/ha productivity. Nitrogen plays a vital role in crucial plant processes like photosynthesis and protein synthesis and aiding nutrient transport. Nano-fertilizers show potential by enhancing nutrient efficiency and penetrating cell walls. They could reduce nutrient losses by synchronizing nutrient release with plant uptake (Lv *et al.*, 2019). Urea-based nanoparticles are now recommended for agricultural nitrogen supplementation (Kiran and Chandra, 2021). Recently, in India, IFFCO has

developed nano-urea, which has been tested at the field research scale to provide essential nitrogen and enhance the effectiveness of various crops, including maize (Upadhyay *et al.*, 2023a). However, limited research has been conducted on studying the interaction effects of different levels of recommended dose of nitrogen (RDN) with nano-urea in maize. The standardization of nano-urea for higher productivity, profitability and economics in maize, especially under acid soil of Jharkhand in rainfed maize needs to be investigated. Validation of nano-urea in rainfed maize under various field conditions is crucial and further research is required to evaluate how well it can be integrated with other nitrogen sources is a new field of inquiry.

The research was conducted at the ICAR-Indian Agricultural Research Institute (IARI) farm in Jharkhand, situated at latitude 24°16' N, longitude 85°21' E and an elevation of 413 meters above sea level. The region experiences a semi-arid, sub-tropical climate with hot and dry summers from May to June and mildly chilly winters from November to January. The average annual rainfall and temperature were recorded at 714 mm and 25°C, respectively. The soil at the experimental site is sandy loam, slightly acidic, with organic carbon, available nitrogen, phosphorus, and potassium levels measured at 0.27%, 147 kg/ha, 8.2 kg/ha and

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136 kg/ha, respectively. A randomized block design (RBD) was used for the experiment with 12 different treatments that were replicated thrice. The treatments were T₁, control i.e. No-Nitrogen(N); T₂, 50% of recommended N; T₃, 75% of recommended N; T₄, 100% of recommended N; T₅, No-N + 2 Sprays of nano-N (NUS), T₆, 50% of recommended N + 2 NUS; T₇, 75% of recommended N + 2 NUS; T₈, 100% of recommended N + 2 NUS; T₉, No-N + 2% prilled urea spray (PUS); T₁₀, 50% of recommended N + 2% PUS; T₁₁, 75% of recommended N + 2% PUS; T₁₂, 100% of recommended N + 2% PUS. The hybrid variety 'DHM-121' was planted on 19 July 2022, and harvested on 6 November 2022. The planting was done with row spacing of 60cm and 20cm distance between plants. Soil preparation involved using a tractor-drawn mould-board plough, cultivator and rotavator, followed by the creation of ridge-furrows using a ridge maker. The field was divided according to the layout plan, including irrigation channels. The recommended dose of fertilizer applied was 150 kg of nitrogen, 75 kg of P₂O₅, and 50 kg of K₂O per hectare. Nano-urea was used at a rate of 500 ml/acre or 4 ml/liter of water. During sowing, the complete doses of phosphorus and potassium, along with one-third of the nitrogen, were applied. The remaining nitrogen was divided into 2-equal portions and applied at 32 and 50 days after sowing (DAS). With the first (32 DAS) and second (50 DAS) split of prilled urea top dressing, nano-urea and prilled urea spray were applied simultaneously. Keeping T₄ as base where RDF was applied, the added cost was ₹521, ₹1,070 and

₹1,500 with nano-urea spray and 50%, 75% and 100% RDN, respectively. Similarly, the added cost over RDF with prilled urea spray and 50%, 75% and 100% RDN was ₹-46, ₹503 and ₹933 respectively.

Different nitrogen levels had a significant effect on cob length (cm), cob girth (cm), number of rows/cobs, grains/row, number of grains/cobs, 1,000-grain weight (gm) and cob yield without husk of maize (Table 1). The highest cob length (cm), cob girth (cm), number of rows/cobs, grains/row, number of grains/cobs and 1,000-grain weight (g) under 100% of recommended N + 2 NUS recorded highest among other treatments.

The highest cob yield without husk was recorded in 100% of recommended N + 2 NUS followed by 100% of recommended N + 2% PUS. and 100% of recommended N. The same results were found by Samui *et al.*, 2022. The grain yield recorded significantly higher in 100% of recommended N + 2 NUS (6.89 t/ha) compared to 100% of recommended N + 2% PUS rest of the treatments (Fig. 1). An increase of 9.43 % in yield was recorded with the application of 100% of recommended N + 2 NUS over 100% of recommended N. 75% of recommended N + 2 NUS recorded at par grain yield over the treatment 100% of recommended N (Sarkar *et al.*, 2023). 100% of recommended N + 2 NUS recorded 66.18, 65.6 and 69.23% increase in grain yield over No N, No-N + 2 NUS and No N + 2% PUS respectively. The need-based nitrogen release from nano-urea enhanced the photosynthesis by ensuring an adequate supply of chlorophyll-protein complexes which

Table 1. Effect of variable nitrogen sources and doses on yield attributes of maize

| Treatment | Cob length (cm) | Cob girth (cm) | Number of rows/cobs | Grains/row | Number of grains/cobs | Cob yield without husk (kg/ha) | 1000-grain weight (gm) | Harvest index (%) |
|-----------------|-----------------|----------------|---------------------|------------|-----------------------|--------------------------------|------------------------|-------------------|
| T ₁ | 11.07 | 10.59 | 9.08 | 23 | 208.9 | 3,843 | 249.69 | 29.49 |
| T ₂ | 14.64 | 11.89 | 11.30 | 26 | 294.4 | 5,405 | 275.29 | 32.83 |
| T ₃ | 17.99 | 15.04 | 12.45 | 28 | 346.6 | 7,154 | 292.46 | 35.28 |
| T ₄ | 19.12 | 15.28 | 12.95 | 30 | 388.8 | 8,616 | 308.21 | 37.52 |
| T ₅ | 12.64 | 13.69 | 9.37 | 23 | 215.3 | 3,867 | 266.23 | 29.90 |
| T ₆ | 15.83 | 14.84 | 11.48 | 27 | 310.5 | 5,464 | 280.54 | 33.70 |
| T ₇ | 19.39 | 16.00 | 12.56 | 29 | 364.2 | 7,455 | 299.70 | 35.99 |
| T ₈ | 19.67 | 16.86 | 13.16 | 31 | 407.1 | 8,867 | 316.25 | 38.12 |
| T ₉ | 12.14 | 13.22 | 9.28 | 23 | 213.0 | 3,554 | 262.29 | 28.72 |
| T ₁₀ | 15.16 | 14.26 | 11.43 | 26 | 295.8 | 5,426 | 274.65 | 33.18 |
| T ₁₁ | 18.57 | 16.01 | 12.49 | 29 | 361.3 | 7,320 | 295.75 | 35.46 |
| T ₁₂ | 19.52 | 16.23 | 12.97 | 31 | 402.6 | 8,678 | 311.21 | 38.13 |
| SEm± | 0.84 | 0.96 | 0.82 | 1.52 | 14.82 | 393.08 | 14.0 | 1.95 |
| CpD (P=0.05) | 2.46 | 2.8 | 2.4 | 4.45 | 43.48 | 1152.9 | 41.0 | 5.72 |

RDN, Recommended Dose of Nitrogen; NUS, Nano-urea Spray; PUS, Prilled Urea Spray; T₁, No-Nitrogen(N); T₂, 50% of recommended N; T₃, 75% of recommended N; T₄, 100% of recommended N; T₅, No-N+2 Sprays of nano-N (NUS); T₆, 50% of recommended N+2 NUS; T₇, 75% of recommended N+2 NUS; T₈, 100% of recommended N+2 NUS; T₉, No-N+2% prilled urea spray (PUS); T₁₀, 50% of recommended N+2% PUS; T₁₁, 75% of recommended N+2% PUS; T₁₂, 100% of recommended N+2% PUS

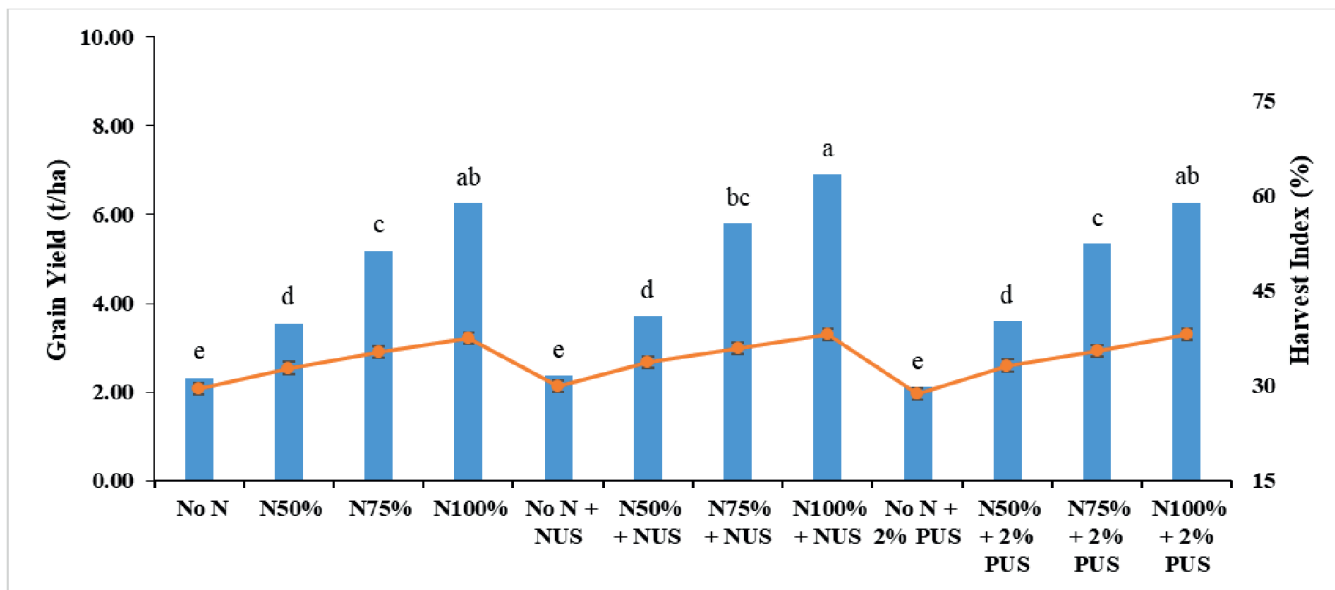


Fig. 1. Effect of variable nitrogen sources and doses on grain yield and harvest index of maize. (Symbol a, b, c, d, e denotes the 5% significant level of difference).

saves from adversity in the crops finally results in improved growth, enhances yield and physiological efficiency (Babu *et al.*, 2022).

The harvest index (HI) is an important metric that expresses how efficiently dry matter was converted into the crop’s economic component. The harvest index of the maize crop differed significantly depending on the level of nitrogen management. 100% of recommended N + 2 NUS and 100% of recommended N + 2% PUS had a significantly higher harvest index (38.1%) than all other nitrogen management practices. No-N + 2% PUS had a lower har-

vest index (28.7%), which was statistically similar to No-N, 50% of recommended N, No-N + 2 NUS, 50% of recommended N + 2 NUS, 50% of recommended N + 2% PUS. These findings are consistent with those reported by Upadhyay *et al.* (2023b).

In terms of net returns and B: C which influenced significantly by different doses of recommended N with nano-urea and prilled urea spray. 100% of recommended N + 2 NUS recorded significantly higher over rest of the treatments and it remained at par with 100% of recommended N and 100% of recommended N + 2% PUS (Fig. 2). 75%

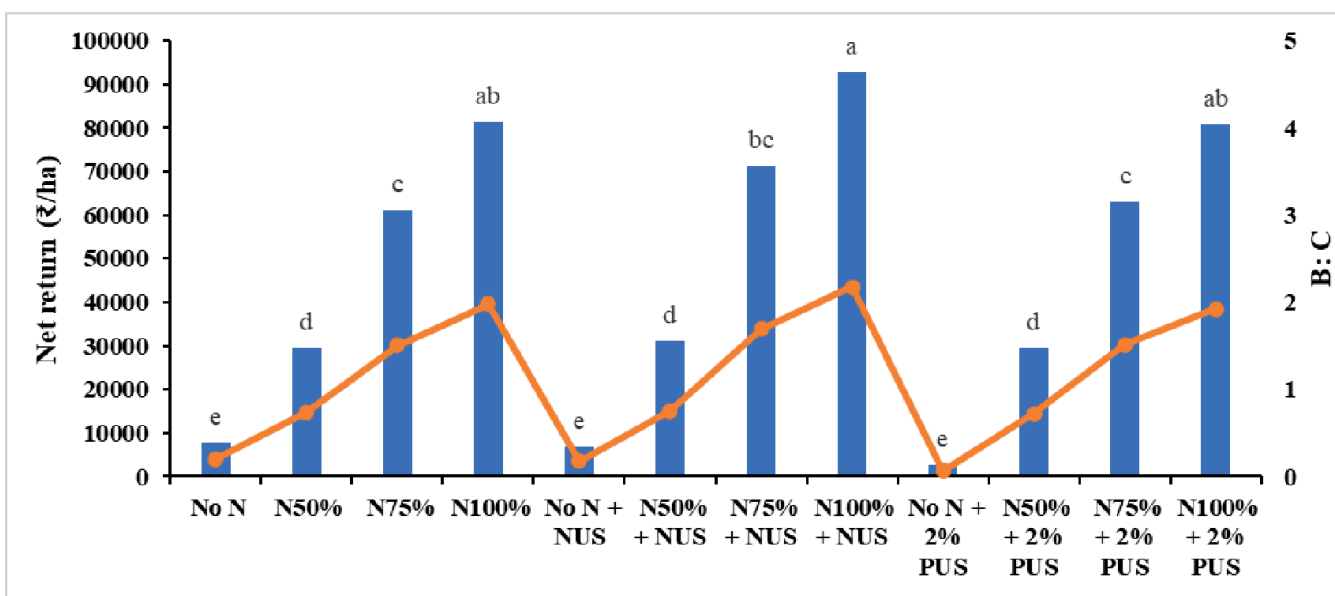


Fig. 2. Effect of variable nitrogen sources and doses on net return and B: C of maize. (Symbol a, b, c, d, e denotes the 5% significant level of difference).

of recommended N + 2 NUS recorded at par net returns and B: C over the treatment 100% of recommended N. The results are in accordance with Upadhyay *et al.* (2023b).

Based on these results, it can be concluded that the possibility of increasing productivity and profitability in maize with use of 2 nano-urea Sprays over and above of 100% recommended dose of conventional urea with full dose of P₂O₅ and K₂O application. The at par results between grain yields and economics in 100% RDN and 75% RDN + 2 NUS suggested further, there is a chance for a curtailing of 25% recommended conventional urea with use of 75% recommended dose of nitrogen through conventional urea with 2 nano-urea spray at 32 and 50 DAS in maize.

REFERENCES

- Babu, S., Singh, R., Yadav, D., Rathore, S.S., Raj, R., Avasthe, R., Yadav, S.K., Das, A., Yadav, V., Yadav, B., Shekhawat, K., Upadhyay, P.K., Yadav, D.K. and Singh, V.K. 2022. Nanofertilizers for agricultural and environmental sustainability. *Chemosphere* **292**: 133451.
- FAOStat. 2021. FAO Stat. FAO, Rome. <http://www.fao.org/faostat>
- Kiran, K. and Chandra, K. 2021. 'Nano Urea Liquid'—A Boon for Indian Farmers and Mother Earth. *Biotechnology Research Today* **3**(6): 511–514.
- Lv, J., Christie, P. and Zhang, S. 2019. Uptake, translocation, and transformation of metal-based nanoparticles in plants: recent advances and methodological challenges. *Environmental Science: Nano* **6**(1): 41–59.
- Sarkar, A., Singh, T., Mondal, A., Kumar, S., Das, T.K., Kaur, R., Raj, R., Upadhyay, P. K. and Sarkar, S. 2023. Effect of nano-urea and herbicides on yield and yield attributes of wheat (*Triticum aestivum*). *Indian Journal of Agronomy* **68**(1): 97–100.
- Samui, S., Sagar, L., Sankar, T., Manohar, A., Adhikary, R., Maitra, S. and Praharaj, S. 2022. Growth and productivity of *rabi* maize as influenced by foliar application of urea and nano-urea. *Crop Research* **57**(3): 136–140.
- Upadhyay, P.K., Singh, V.K., Rajanna, G.A., Dwivedi, B.S., Dey, A., Singh, R.K., Rathore, S.S., Shekhawat, K., Babu, S., Singh, T., Kumar, Y., Singh, C., Rangot, M., Kumar, A., Sarkar, S., Dash, S. and Rawat, S. 2023b. Unveiling the combined effect of nano fertilizers and conventional fertilizers on crop productivity, profitability, and soil well-being. *Frontiers in Sustainable Food Systems* **7**: 1260178. doi: <https://doi.org/10.3389/fsufs.2023.1260178>.
- Upadhyay, P.K., Dey, A., Singh, V.K., Dwivedi, B.S., Singh, T., Rajanna, G.A., Babu, S., Rathore, S.S., Singh, R.K., Shekhawat, K., Meenakshi, Kumar, P., Yadav, D., Singh, D.P., Dasgupta, D. and Shukla, G. 2023a. Conjoint application of nano-urea with conventional fertilizers: An energy efficient and environmentally robust approach for sustainable crop production. *Plos One*: <https://doi.org/10.1371/journal.pone.0284009>.

Effect of different sources of nitrogen on productivity, profitability and N use efficiency of fodder oat (*Avena sativa*)

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ABSTRACT

A field experiment was conducted during the *rabi* season of 2020-21, to assess the effect of different source of nitrogen on fodder yield, economics and N use efficiency of oat (*Avena sativa* L.). The experiment consisted of seven treatments viz. control (no N); recommended dose of N (RDN); 50% N through fertilizer + 50% N through FYM; 50% N through fertilizer + 50% N through vermicompost; 50% N through fertilizer + two sprays of nano-urea; two spray of nano-urea and site-specific nitrogen management (SSNM). Results showed that application of 50% RDN through fertilizer + two sprays of nano-urea produced 58.3 t/ha green fodder which was at par with all other treatments except two sprays of nano urea and control. However, green fodder yield reduced under two foliar sprays of nano-urea by 20.7% as compared to 100% RDN (59.2 t/ha). The SSNM treatment recorded the highest net returns (₹ 49947/ha) and benefit to cost ratio (1.45) which were significantly higher than all other treatments except 100% RDN and 50% RDN through fertilizer + two sprays of nano-urea. The nano-urea treatments exhibited the highest nitrogen use efficiency. The study suggested that 50% recommended dose of nitrogen through conventional fertilizer along with two sprays of nano-urea could be applied in oat to get higher nitrogen use efficiency without any yield reduction.

Key words: Fodder yield, Nano-urea, Organic manure, N use efficiency

Nitrogen (N) is the most important nutrient for forage crops. It has great significance due to its role in enhancing luxuriant vegetative growth, higher biomass and quick regeneration following cutting or defoliation (Choudhary *et al.*, 2018). Most N management studies have shown a linear increase in biomass yield with incremental increases in N applications (Choudhary and Prabhu, 2016; Finch *et al.*, 2023). Further, optimum N nutrition improves leaf to stem ratio, succulence and palatability of forage crops. Nitrogen fertilization also influences nutritional value in forages. The majority of farmers apply N through urea. Since it is easy to use, cost effective and quick nutrient suppliers. Conventional fertilizers offer nutrients in chemical forms that are not often fully accessible to plants. Despite the excessive use of mineral N fertilizer, a huge amount is lost and/or unavailable to plants. Moreover, sole mineral fertilizer based on a part of M.Sc. Thesis of the first author submitted to ICAR-Indian Grassland and Fodder Research Institute, Jhansi, Uttar Pradesh in 2021 (unpublished)

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zation enhances the decomposition of soil organic matter, which leads to degraded soil structure and declined soil aggregation and loss of nutrients through leaching, fixation, and greenhouse gases emission (Iqbal *et al.*, 2019). Additionally, the use of inorganic fertilizers on soil over long periods of time may affect its capability to maintain healthy crop growth and productivity. In contrast to inorganic fertilizer, organic manure has multiple benefits like improving soil physical and chemical properties, enhanced soil microbial activity (Choudhary *et al.*, 2023). This can improve soil nutrients availability for crop growth and development. However, organic fertilizer is quite low in nutrient content and its nutrient releasing ability is also low to meet crop requirements in a short time, hence the sole application of manure could not meet the usual intensity of agriculture production. Organic manure coupled with synthetic fertilizers has been confirmed to be a better approach to improve and sustain soil fertility and crop production than the sole application of mineral or organic manure (Paramesh *et al.*, 2023).

Several innovations have been done in the area of plant nutrition in order to improve nutrient use efficiency by reducing nutrient loss. Development of nano-fertilizers is one

of the important innovations among them. Some beneficial effects include increase in nutrient use efficiency, better yield and reduced soil pollution. Applying nano-fertilizers can also reduce environmental pollution than traditional chemical fertilizers applied with high rates. Nano-fertilizers possess unique features which enhance plants' performance in terms of ultrahigh absorption, increase in production, rise in photosynthesis, and significant expansion in the leaves' surface area (Kumar *et al.*, 2023). The IFFCO invented and released nano-urea as an alternative to commercial urea. Nano Urea (Liquid) contains 4% (40000 ppm) nanoscale nitrogen particles which have more surface area (10,000 times over 1 mm Urea prill) and number of particles (55,000 nitrogen particles over 1 mm Urea prill) which makes it more impactful. Despite of having numerous advantages of using nano materials in agriculture, the application and popularity of such inputs is very less. Thus, keeping these facts in view, an experiment was carried out to assess the effect of different sources of nitrogen on fodder yield, economics and N use efficiency in oat.

A field experiment was carried out at The Central Research Farm of Indian Grassland and Fodder Research Institute Jhansi, India (25°27'N latitude, 78°33'E longitude and 270 m above mean sea level) during *Rabi* 2020-21. The soil of experimental site was clay loam in texture, neutral in reaction (pH 7.2), medium in organic carbon (6.3 g/kg soil), low in available nitrogen (206 kg/ha) and medium in available P (11.4 kg/ha) and K (230 kg/ha). The experiment was laid out in randomized block design with three replications. The experiment comprised of seven treatments T₁, control (No N); T₂, 100% recommended dose of N (100 kg/ha through fertilizer in 2 splits, half of the dose at the time of sowing and remaining dose at first irrigation (25 DAS) as top dressing); T₃, 50% RDN through fertilizer + 50% N through FYM; T₄, 50% RDN through fertilizer + 50% N through vermicompost; T₅, 50% RDN through fertilizer + two spray of nano-urea; T₆, two spray of nano-urea (2 ml/l at 30 and 50 DAS); T₇, site specific nitrogen management (SSNM). In T₇, 30 kg N was applied at the time of sowing; 30 kg at first irrigation; and 30 kg N was applied at second irrigation (50 DAS) when SPAD meter reading reached < 37. In T₃ to T₅, fertilizer (50 kg N/ha) was applied as basal at the time of sowing. However, organic manure was applied at the time of field preparation. A uniform dose of 60 kg P₂O₅ and 40 kg K₂O per hectare was applied at the time of sowing. Oat variety 'JHO-822' was sown at 25 cm row spacing at about 3-4 cm depth through seed drill using seed rate of 100 kg/ha. Oat crop was harvested at 50% flowering stage and weighed for green fodder yield. In general, four terms are used in relation to nitrogen use efficiency: Partial Factor Productivity (PFP), Agronomic Efficiency (AE), Recovery Efficiency

(RE) and Physiological Efficiency (PE). The following expressions were used to determine these efficiencies as suggested by Congreves *et al.* (2021):

$$\text{PFP (kg DM yield per kg N applied)} = Y_f / N_a$$

$$\text{AE (kg DM yield increased per kg N applied)} = (Y_f - Y_c) / N_a$$

$$\text{RE (\% of N taken up by a crop)} = [(N_{Uf} - N_{Uc}) / N_a] \times 100$$

$$\text{PE (kg DM yield increased per kg N uptake)} = [(Y_f - Y_c) / (N_{Uf} - N_{Uc})] \times 100$$

Where, Y_f and Y_c are the DM yields (t/ha) in fertilized and control (no N) plots, respectively. N_{Uf} and N_{Uc} are the amounts of N taken up by oat crop in fertilized and control plots, respectively and N_a refers to the amount of N applied (kg/ha).

Benefit to cost ratio was calculated by dividing the net returns value to the production cost in order to determine the economic efficiency. Data were subjected to analysis of variance (ANOVA) using SAS 9.3 (SAS Institute, Cary, NC, USA). Fischer's protected least significant difference (LSD) test was used to test the differences between treatment means at P < 0.05.

Green fodder yield of oat was significantly influenced by different sources of N fertilization (Table 1). Application of 50% RDN through fertilizer + 50% N through vermicompost produced significantly the highest green fodder yield (61.1 t/ha) followed by SSNM which was doubled than control. Furthermore, green fodder yield reduced by 20.7% under two foliar spray of nano-urea compared to 100% RDN (59.2 t/ha). However, 50% RDN-fertilizer + two sprays of nano-urea recorded statistically at par but numerically different fodder yield as of 100% RDN. This is possibly due to the synchronous release of N from the nano-urea following the demand of the crop. Upadhyay *et al.* (2023) reported that application of two sprays of nano-urea in combination of fertilizer may curtail 25% of the recommended dose of N in maize-wheat and pearl millet-mustard cropping systems. However, Sarkar *et al.* (2023) found reduction in the yield of wheat by 28.6% under 50% RDF + two spray of nano-urea.

Integrated use of fertilizer (50% N) and organic manures (50% N) recorded the statistically at par yield with 100% RDN through fertilizer alone. Organic manure (FYM and vermicompost) acts as a substrate for microorganisms which brings about the transformation of unavailable form of nutrients present in soil and applied as fertilizer in available form which are readily utilized by growing plants and also improve soil condition, favourable for availability of nutrients to crop (Ma *et al.*, 2020). Therefore, synergistic effect of organic manure with fertilizer resulted in higher fodder yield.

The production cost of oat varied from minimum with

control (₹ 32760/ha) to maximum under 50% RDN through fertilizer + 50% N through VC (₹ 49110/ha) (Table 1). The cost of cultivation with 50% RDN through fertilizer + two sprays of nano-urea was comparatively higher than 100% RDN through fertilizer due to spraying cost of nano-urea. The maximum gross returns were calculated in 50% RDN through fertilizer + 50% N through VC (₹ 85493/ha) and minimum in control (₹ 10267/ha). The higher green fodder yields in fertilizer treatments also believed to be reason for the higher gross returns. However, the maximum net returns were computed in SSNM (₹ 49947/ha). Like net returns, highest benefit to cost ratio was calculated in SSNM (1.45) followed by RDN (1.41) and lowest in control (0.31). Integration of organic manure (FYM and vermicompost) with fertilizer also increased the cost of treatment, therefore, reduced the economic returns as compared to chemical fertilizers. Lower benefit to cost ratio under organic manure treatments mainly because of proportionate returns from manure was less in comparison to cost involved.

Data on nitrogen-use indices like partial factor productivity (PFP), agronomic efficiency (AE), recovery efficiency (RE) and physiological efficiency (PE) of oat are presented in Table 1. The highest partial factor productivity (188 kg DM/kg N applied), agronomic efficiency (83 kg DM increased/kg N applied) and recovery efficiency (175%) were computed with application 50% RDN through fertilizer + two spray of nano-urea followed by SSNM. However, maximum physiological efficiency (54.3 kg DM increased/kg N uptake increased) was computed under nano-urea spray treatment. Synchronizing crop N demand with fertilizer N supply using SPAD meter-based N management (SSNM) strategy led to higher AE and RE

of applied N. In this study, higher PFP and AE under nano-urea treatments was mainly due to lower N application without much compromising fodder yield. Foliar application of nano-fertilizers can enter plants through the epidermis or stomata and then translocate through the apoplast or symplast pathways, which enhances nitrogen use efficiency. Kottegoda *et al.* (2017) in field conditions the nitrogen agronomic efficiency was 48% for nano-urea while in the case of urea it was 18% demonstrating that the expected slower N release by nano-urea resulted in a better N-efficiency compared to traditional fertilizer. Higher efficiency of nano fertilizer was also reported by Upadhyay *et al.* (2023).

Total uptake of nutrients (N, P and K) by oat crop was significantly ($P < 0.05$) influenced with diverse nitrogen fertilization (Fig 1). The uptake of nutrients is in the order of $N > K > P$. In general, N uptake is 6 to 7 times of P uptake. Significantly maximum uptake of N (194 kg/ha) and K (150 kg/ha) was recorded in SSNM while 50% N-fertilizer

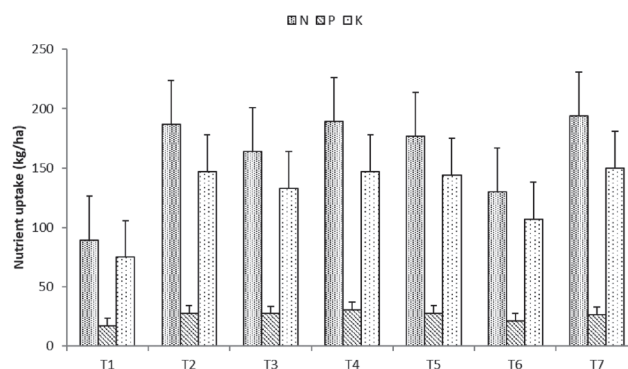


Fig. 1. Effect of different source of nitrogen on nutrient uptake in oat. Error bar represents LSD at 5% level of significance.

Table 1. Effect of different source of nitrogen on fodder yield and economics of oat

| Treatments | Green fodder yield (t/ha) | Total cost (₹/ha) | Gross returns (₹/ha) | Net returns (₹/ha) | BCR | N Use Efficiency | | | |
|---------------------------------------|---------------------------|-------------------|----------------------|--------------------|------|------------------|----|-----|------|
| | | | | | | PFP | AE | RE | PE |
| Control (No N) | 30.7 | 32,760 | 43,027 | 10,267 | 0.31 | - | - | - | - |
| 100% RDN | 59.2 | 34,410 | 82,833 | 48,423 | 1.41 | 99 | 46 | 97 | 47.2 |
| 50% N-fertilizer + 50% N-FYM | 56.4 | 42,793 | 78,913 | 36,120 | 0.84 | 90 | 38 | 75 | 50.4 |
| 50% N-fertilizer + 50% N-vermicompost | 61.1 | 49,110 | 85,493 | 36,383 | 0.74 | 102 | 49 | 100 | 49.6 |
| 50% N-fertilizer + nano-urea spray | 58.3 | 34,940 | 81,573 | 46,633 | 1.33 | 188 | 83 | 175 | 47.5 |
| Nano-urea spray* | 47.0 | 34,240 | 65,753 | 31,513 | 0.92 | - | - | - | 54.3 |
| SSNM | 60.3 | 34,520 | 84,467 | 49,947 | 1.45 | 112 | 53 | 116 | 45.7 |
| SEm± | 2.66 | | 3,722 | 3,722 | 0.10 | | | | |
| LSD (P=0.05) | 8.19 | | 11,468 | 11,468 | 0.30 | | | | |

SSNM– site specific nutrient management; PFP–partial factor productivity (kg DM/kg N applied); AE–agronomic efficiency (kg DM increased/kg N applied); RE–recovery efficiency (%); PE–physiological efficiency (kg DM increased/kg N uptake increased)

*In this treatment, very minute quantity of N was applied through Nano-urea resulting very high values of PFP, AE and RE. Hence, data was not provided.

+ 50% N-vermicompost recorded maximum uptake of P (30.8 kg/ha). Furthermore, control recorded least uptake of N (89 kg/ha), P (17 kg/ha) and K (75 kg/ha) followed by two spray of nano-urea. The nutrient uptake in crop is largely dependent on dry matter accumulation and nutrient concentration in plant and available nutrient status in the soil. The uptake increased in aforesaid treatments because of higher availability of these nutrient and biomass yield. Similar results were reported by Kumar *et al.* (2021).

It can be concluded that oat crop should be fertilized with 50% recommended dose of N through fertilizer + two sprays of nano-urea at 30 and 50 days after sowing for achieving higher productivity, profitability and nitrogen-use efficiency. However, the findings of the nano-urea need to be further validated in long term experiments.

REFERENCES

- Choudhary, M., and Prabhu, G. 2016. Response of fodder oat (*Avena sativa* L.) varieties to irrigation and fertilizer gradient. *Range Management and Agroforestry* **37**(2): 201-206.
- Choudhary, M., Prabhu, G. and Palsaniya, D.R. 2018. Response of guinea grass (*Megathyrsus maximus*) genotypes to intercropping with forage legumes under varying nitrogen management options. *Grass and Forage Science* **73**: 888-896.
- Choudhary, P., Prasad, M., Choudhary, M., Kumar, A., Kumar, S., Srinivasan, R. and Mahawer, S.K. 2023. Exploring invasive weed biochar as soil amendment: A study on fodder oats productivity and soil biological properties. *Environmental Research* **216**: 114527.
- Congreves, K.A., Otchere, O., Ferland, D., Farzadfar, S., Williams, S. and Arcand, M.M. 2021. Nitrogen use efficiency definitions of today and tomorrow. *Frontiers in Plant Science* **12**: 637108.
- Finch, B., Souza, J.L.B., Reed, V., Sharry, R., Smith, M. and Arnall, D.B. 2023. Evaluation of nitrogen and cropping system management in continuous winter wheat forage production systems. *Agronomy* **13**(1): 262.
- Iqbal, A., He, L., Khan, A., Wei, S., Akhtar, K., Ali, I., Ullah, S., Munsif, F., Zhao, Q. and Jiang, L. 2019. Organic manure coupled with inorganic fertilizer: An approach for the sustainable production of rice by improving soil properties and nitrogen use efficiency. *Agronomy* **9**(10): 651.
- Kottegoda, N., Sandaruwan, C., Priyadarshana, G., Siriwardhana, A., Rathnayake, U.A., Arachchige, D.B., Kumarasinge, A., Dahanayake, D., Karunaratne, V. and Amaratunga, G. 2017. Urea-hydroxyapatite nanohybrids for slow release of nitrogen. *ACS Nano* **11**: 1214–1221.
- Kumar, D., Singh, M., Kushwaha, M., Makarana, G. and Yadav, M.R. 2021. Integrated use of organic and inorganic nutrient sources influences the nutrient content, uptake and nutrient use efficiencies of fodder oats (*Avena sativa*). *Indian Journal of Agronomy* **66**(4): 466-473.
- Kumar, N., Samota, S.R., Venkatesh, K. and Tripathi, S.C. 2023. Global trends in use of nano-fertilizers for crop production: Advantages and constraints—A review. *Soil and Tillage Research* **228**: 105645.
- Ma, Q., Y. Wen, D. Wang, X. Sun, P.W. Hill, A. Macdonald, D.R. Chadwick, L. Wu and D.L. Jones. 2020. Farmyard manure applications stimulate soil carbon and nitrogen cycling by boosting microbial biomass rather than changing its community composition. *Soil Biology and Biochemistry* **144**: 107760.
- Paramesh, V., Kumar, R.M., Rajanna, G.A., Gowda, S., Nath, A.J., Madival, Y., Jinger, D., Bhat, S. and Toraskar, S. 2023. Integrated nutrient management for improving crop yields, soil properties, and reducing greenhouse gas emissions. *Frontiers in Sustainable Food Systems* **7**: 1173258.
- Sarkar, A., Singh, T., Mondal, A., Kumar, S., Das, T.K., Kaur, R., Raj, R., Upadhyay, P.K. and Sarkar, S. 2023. Effect of nano-urea and herbicides on yield and yield attributes of wheat (*Triticum aestivum*). *Indian Journal of Agronomy* **68**(1): 97-100.
- Upadhyay, P.K., Dey, A., Singh, V.K., Dwivedi, B.S., Singh, T., G.A., R., Babu, S., Rathore, S.S., Singh, R.K., Shekhawat, K. and Rangot, M. 2023. Conjoint application of nano-urea with conventional fertilizers: An energy efficient and environmentally robust approach for sustainable crop production. *Plos One* **18**(7): p.e0284009.

Effect of seed priming and seed rate on the performance of wheat (*Triticum aestivum*)

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ABSTRACT

A field experiment was carried out to determine the impact of different seed rates and priming strategies on germination percentage, growth attributes, and yield of wheat (*Triticum aestivum* L.). The experiment comprised twelve treatments i.e. surface seeding with no seed priming, priming for 12 hours in water, 1% KNO₃, and 1% CaCl₂ at 100, 125, and 150 kg/ha seed rates. The results indicated that the highest final germination percentage (84%) at 10 DAS was found with seed priming with 1% CaCl₂ at a 100 kg/ha seed rate. The tallest plant was observed with seed priming with 1% CaCl₂ at 150 kg/ha seed rate. However, number of tiller/m² and dry matter accumulation was recorded maximum with seed priming with 1% CaCl₂ at 150 kg/ha seed rate, which was 7.27% and 20% higher compared to number of tillers/m² and dry matter accumulation under dry seed surface seeding with 100 kg/ha seed rate, respectively. The highest grain yield (4662 kg/ha) and straw yield (5694 kg/ha) were found with seed priming with 1% CaCl₂ at 150 kg/ha seed rate. Similarly, maximum gross (₹114851/ha) and net (₹76884/ha) returns were obtained in seed priming with 1% CaCl₂ at 150 kg/ha seed rate but the highest B: C ratio (3.09) was obtained with seed priming with 1% CaCl₂ at 125 kg/ha seed rate. Hence, adopting seed priming strategies at different seed rates can improve the growth and yield of wheat.

Key words: Germination percentage, Growth attributes, Seed priming, Seed rate, Wheat, Yield

Wheat (*Triticum aestivum* L.) is the most valuable cereal crop and the primary source of food and nutrition for the world's population. India ranked second in wheat production with a crop of 112.8 million metric tonnes an area of 32.0 million ha and productivity of 3.56 t/ha. The area, production, and productivity of wheat in Bihar are 2.20 Mha, 6.72 Million tonnes, and 2.872 t/ha, respectively (Directorate of Economics and Statistics, Ministry of Agriculture & Farmers' Welfare, Government of India, 2022-23). There are different methods of sowing for wheat crops such as broadcasting, broad bed furrow, dibbling, and surface seeding (Singh *et al.*, 2013). In surface seeding, seeds are broadcast-cast on the surface without any field preparation. Surface seeding is adopted in areas where excess moisture is present in the soil as there may be issues during tillage operation and land preparation (Sharma *et al.*, 2024). In surface seeding, there are high chances of seeding mortal-

ity as the upper layer of the soil surface becomes dry as compared to the layers beneath the soil surface resulting in reduced moisture for the germination of seed. This problem can be mitigated by increasing the seed rate and adopting seed priming methods (Ambreen *et al.*, 2021). Seed priming is a useful technique for achieving fast and uniform emergence along with high vigor, which leads to improved crop establishment and yield benefits in a variety of field crops, including cereals (Abou-Zeid *et al.*, 2021; Paswan *et al.*, 2023). Moreover, the seed rate of the crop is an important factor that determines the ability of plants to utilize available resources (Sheteiwy *et al.*, 2017). To get a higher germination percentage and wheat yield under surface seeding, the optimum seed rate with proper seed priming strategies should be adopted and hence optimization of these parameters needs to be studied.

The field experiment was conducted at Pusa farm, Dr. Rajendra Prasad Central Agricultural University, Pusa, Bihar during the *rabi* season of 2020-21. Geographically, Pusa is situated at 25°60' North latitude, 85°76' East longitude, and 51.3 meters above mean sea level. It comes under the subtropical zone and is near the Burhi Gandak River in North Bihar. The experiment was laid out in a randomized complete block design (RCBD) and replicated

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thrice. There were twelve treatments *viz.*, surface seeding of dry seed with 100, 125, and 150 kg/ha seed rate; surface seeding of soaked seed with 100, 125, and 150 kg/ha seed rate; seed priming with 1% KNO₃ at 100, 125 and 150 kg/ha seed rate; seed priming with 1% CaCl₂ at 100, 125 and 150 kg/ha seed rate. The variety HD 2967 was used in the experiment. The recommended dose of N: P₂O₅:K₂O was 120:60:40 kg/ha. Urea, DAP, and MOP were the sources of fertilizers used in the experimental field. As a basal dose, ½ dose of N was added along with the full dose of P₂O₅ and K₂O, while the remaining dose of N was applied in two equal split doses of ½ N was applied after the first irrigation and a second split dose of ½ N was applied after second irrigation. The soil of the experimental field was low in available N (195.8 kg/ha), low in organic carbon (0.43%), medium in available P (21.28 kg/ha), and medium in K (124.3 kg/ha). Soil pH (8.4) was alkaline in nature.

For seed priming, 1 kg wheat seeds were soaked in water, 1% KNO₃, and CaCl₂ solution for 12 hours. The solution of KNO₃ and CaCl₂ was prepared by dissolving 10 g of KNO₃ and KCl, respectively in 1 L of water. After soaking of seed for 12 hours, the priming solution was drained off. Thereafter, seeds were shade-dried until they reached the original seed moisture content (determined by the seed moisture meter) which was 12%. Sowing was done manually as surface seeding in definite rows at 20 cm row-to-row spacing. Sowing was done with dry seeds as well as overnight pre-soaking priming seeds with hydropriming, CaCl₂, and KNO₃ for 12 hours. Surface seeding as well as seed priming was carried out following seed rates of 100, 125, and 150 kg/ha.

The germination percentage is the ratio of germinated seed to total seed used for sowing purposes. For estimating germination percentage count, the total germinated seedling from 1m length from each experimental plot was counted. Then, the germination percentage is calculated from the ratio of germinated seed to total seed used for sowing purposes. The germination percentage was calculated following the first count, second, and third count on the fifth, seventh day, and tenth day of germination for normal seedlings respectively. Seedling length is the total sum of the length of coleoptile and coleorhiza. For calculating seedling length, five normal seedlings were chosen from the randomly selected experimental plot, and the seedlings were uprooted carefully in such a way that the root of seedlings would not be damaged. The soil is removed from the base of the seedling and the total length of the chosen seedling is measured at 5, 7, and 10 days after sowing (DAS) and weighed without drying for taking fresh biomass. The seedling vigor index indicates the robustness and hardiness of the seedling to a contingent environment and other competitive factors. The seedling vigor index

was determined using the formula given below, which was suggested by Abdul-Baki and Anderson (1973).

Seedling Vigour Index (VI) = Germination (%) × Seedling length (cm)

Five randomly selected plants from each experimental plot were taken into observation to estimate plant height and number of tillers/m² at 30, 60, and 90 DAS and at harvest. In the case of dry matter accumulation five random plants were taken from each experiment plot and cut over the ground level with a sickle at 30, 60, 90 DAS, and at harvest. For 48 hours, these plants were sundried. After sun drying, these plants were dried in an oven at 65°C for 48–72 hours. Plants were harvested at maturity and the harvested net area of each plot was threshed and cleaned to obtain the produce (grains) from whole biomass. Thereafter, the grain yield from each plot was recorded in kg per plot and changed over to t/ha. The harvest index was calculated with the help of the following formula:

$$\text{Harvest Index (\%)} = \frac{\text{Grain yield}}{\text{Biological (grain+straw) yield}} \times 100$$

The data generated from the field experiment was analyzed using “Analysis of Variance” (ANOVA) in RBD as suggested by Gomez and Gomez (1984). The standard error of the mean (SEm±) and critical difference (CD) at a 5% level of significance was calculated for each character to compare the treatment difference. Statistical analysis was performed in SPSS version 16.0 (SPSS Inc., Chicago, USA).

Germination percentage is an important characteristic for any plant species because plant stand depends on germination percentage, plant genotype, and climatic factors. The maximum germination percentage *i.e.*, 69%, 80%, and 84% at 5, 7, and 10 DAS, respectively was recorded highest in seed priming with 1% CaCl₂ at 100 kg/ha seed rate (Table 1). This might be due to the activation of reserve amylase content that acts as a catalyst for the secretion of hydrolase from the aleurone layer and helps in starch and sugar reduction. Reduction of starch and sugar helps in early germination and provides nutrition to germinated seeds. These results are in conformity with the findings of Dayal *et al.* (2023), Khaing *et al.* (2020), and Sow *et al.* (2023).

The analysis of data from various treatments revealed that the highest seedling length at 5 DAS (95 mm), 7 DAS (160 mm), and 10 DAS (216 mm) was recorded by adopting seed priming with 1% CaCl₂ at 100 kg/ha seed rate (Table 1). The minimum seedling length at 5 DAS (65 mm), 7 DAS (118 mm), and 10 DAS (175 mm) were found with dry seed surface seeding at 150 kg/ha seed rate. This was due to the effect of priming which activates reserve amylase content and helps in early germination as well as establishment of radicle. It leads to better crop establishment and an increase in seedling length. On the other hand,

Table 1. Effect of different seed priming methods and seed rate on seed quality parameters of wheat

| Treatments | Germination percentage | | | Seedling length (mm) | | | Seedling fresh weight (mg) | | | Seedling vigour index | | |
|-----------------|------------------------|-------|--------|----------------------|-------|--------|----------------------------|-------|--------|-----------------------|-------|--------|
| | 5 DAS | 7 DAS | 10 DAS | 5 DAS | 7 DAS | 10 DAS | 5 DAS | 7 DAS | 10 DAS | 5 DAS | 7 DAS | 10 DAS |
| T ₁ | 60 | 75 | 77 | 70 | 127 | 184 | 980 | 1,160 | 1,230 | 420 | 952 | 1,416 |
| T ₂ | 59 | 72 | 75 | 67 | 122 | 180 | 920 | 1,157 | 1,224 | 395 | 878 | 1,350 |
| T ₃ | 57 | 71 | 74 | 65 | 118 | 175 | 870 | 1,020 | 1,180 | 370 | 837 | 1,295 |
| T ₄ | 64 | 76 | 79 | 90 | 155 | 209 | 1,104 | 1,185 | 1,415 | 576 | 1,178 | 1,630 |
| T ₅ | 62 | 74 | 76 | 80 | 141 | 190 | 1,017 | 1,178 | 1,354 | 496 | 1,043 | 1,444 |
| T ₆ | 61 | 72 | 73 | 72 | 133 | 182 | 875 | 1,022 | 1,217 | 439 | 957 | 1,328 |
| T ₇ | 66 | 78 | 81 | 93 | 157 | 213 | 1,110 | 1,192 | 1,422 | 613 | 1,291 | 1,725 |
| T ₈ | 65 | 75 | 79 | 85 | 145 | 196 | 1,020 | 1,180 | 1,359 | 552 | 1,176 | 1,572 |
| T ₉ | 62 | 74 | 76 | 76 | 135 | 185 | 882 | 1,025 | 1,220 | 471 | 1,065 | 1,406 |
| T ₁₀ | 69 | 80 | 84 | 95 | 160 | 216 | 1,115 | 1,205 | 1,430 | 655 | 1,346 | 1,814 |
| T ₁₁ | 67 | 77 | 82 | 88 | 148 | 208 | 1,035 | 1,184 | 1,365 | 589 | 1,229 | 1,664 |
| T ₁₂ | 64 | 76 | 79 | 77 | 139 | 189 | 971 | 1,150 | 1,218 | 492 | 1,488 | 1,474 |
| SEm± | 1.02 | 1.67 | 1.81 | 3.32 | 4.18 | 6.32 | 6.98 | 12.93 | 13.57 | 16 | 29 | 38 |
| CD (P=0.05) | 3.0 | 4.92 | 5.31 | 10.25 | 12.49 | 19.02 | 20.48 | 37.94 | 39.81 | 47 | 87 | 112 |

T₁, dry seed surface seeding with 100 kg/ha seed rate; T₂, dry seed surface seeding with 125 kg/ha seed rate; T₃, dry seed surface seeding with 150 kg/ha seed rate; T₄-12 hours soaked seed surface seeding with 100 kg/ha seed rate; T₅, 12 hours soaked seed surface seeding with 125 kg/ha seed rate; T₆, 12 hours soaked seed surface seeding with 150 kg/ha seed rate; T₇, seed priming with 1% KNO₃ at 100 kg/ha seed rate; T₈, seed priming with 1% KNO₃ at 125 kg/ha seed rate; T₉, seed priming with 1% KNO₃ at 150 kg/ha seed rate; T₁₀, seed priming with 1% CaCl₂ at 100 kg/ha seed rate; T₁₁, seed priming with 1% CaCl₂ at 125 kg/ha seed rate; T₁₂, seed priming with 1% CaCl₂ at 150 kg/ha seed rate

with an increase in seed rate a decrease in seedling length was found in the results. This is due to a rise in amylase and hydrogenase activity, which augmented starch reduction that acts as an energy for increasing metabolic activity, and O₂ demand of seed. Therefore, with an increased seed rate, there was more competition for proper O₂ requirements and natural resources. Therefore, seedling length decreased with an increase in seed rate. These results conform with the findings of Sharma *et al.* (2022).

Among different treatments, seedling fresh weight was significantly varied with different seed rates and priming techniques. Seed priming with 1% CaCl₂ at 100 kg/ha (T₁₀) seed rate recorded maximum seedling fresh weight of 1115 mg, 1205 mg, and 1430 mg at 5, 7, and 10 DAS, respectively (Table 1). This was due to an increase in seed rate and priming chemicals *i.e.*, KNO₃ and CaCl₂ which activate reserve amylase content and help in early germination, early emergence, better crop establishment, and increased dry matter accumulation. However, with increased seed rate there was more competition among the emerging seedlings for water, nutrients, space, and other natural resources so a decrease in the fresh weight of seedlings was observed. The results corroborate the findings of Sneha *et al.* (2024).

Seed priming with 1% CaCl₂ at 100 kg/ha (T₁₀) seed rate recorded the highest seedling vigor index of 655, 1346, and 1814 at 5, 7, and 10 DAS, respectively (Table 1). The lowest germination percentage at 5, 7, and 10 DAS *i.e.*, 370,

837, and 1295 was found with dry seed surface seeding at 150 kg/ha seed rate. This was due to higher seedling length and germination percentage in seed priming with 1% CaCl₂ at 100 kg/ha seed rate (T₁₀) compared to other treatments.

Plant height was significantly varied during the experiment period (Table 2). Plant height at 30 (25.91 cm), 60 (68.01 cm), 90 (95.53 cm) DAS and harvest stage (100.53 cm) was recorded highest with the adoption of seed priming with 1% CaCl₂ at 150 kg/ha seed rate (T₁₂). The minimum plant height of 20.18 cm, 60.41 cm, 92.81 cm, and 94.33 cm was found under dry seed surface seeding at 100 kg/ha seed rate. This can be due to salt priming with CaCl₂ and KNO₃ combined with a high seed rate. Plant height increased with increasing seed rate because there was more competition for space and sunlight in higher seed rate so plants increased their height for taking optimum sunlight. Seed priming with 1% CaCl₂ at 150 kg/ha seed rate recorded a maximum number of tillers m² at 30 (242), 60 (306), 90 (362) DAS and at harvest (348). It can be deduced from the results that both factors *i.e.* seed rate and priming techniques lead to the production of a greater number of tillers/m² (Table 2). Similar findings were also reported by Farooq *et al.* (2017) and Iqbal *et al.* (2020).

Dry matter accumulation is the process of storage of photosynthates in the different plant parts. It continuously increases from germination to harvesting. Dry matter accumulates till the vegetative stage and is mainly stored in vegetative parts after that it is stored in reproductive parts

Table 2. Growth and yield attributing characters of wheat affected by different seed priming methods and seed rate

| Treatment | Plant height (cm) | | | | No. of tillers/m ² | | | | Dry-matter accumulation (g/m ²) | | | |
|-----------------|-------------------|--------|--------|---------------|-------------------------------|--------|--------|---------------|---|--------|--------|---------------|
| | 30 DAS | 60 DAS | 90 DAS | At harvesting | 30 DAS | 60 DAS | 90 DAS | At harvesting | 30 DAS | 60 DAS | 90 DAS | At harvesting |
| T ₁ | 20.18 | 60.41 | 89.27 | 94.33 | 227 | 295 | 348 | 330 | 59 | 485 | 690 | 828 |
| T ₂ | 20.95 | 62.41 | 91.93 | 95.87 | 234 | 301 | 354 | 338 | 65 | 490 | 698 | 900 |
| T ₃ | 23.30 | 65.45 | 93.0 | 97.73 | 237 | 304 | 357 | 342 | 69 | 494 | 704 | 950 |
| T ₄ | 21.09 | 63.22 | 92.0 | 97.67 | 230 | 297 | 353 | 335 | 61 | 489 | 694 | 843 |
| T ₅ | 21.85 | 64.82 | 93.12 | 98.25 | 238 | 305 | 359 | 345 | 71 | 499 | 708 | 998 |
| T ₆ | 24.70 | 66.60 | 94.0 | 99.63 | 242 | 306 | 362 | 348 | 74 | 503 | 712 | 1,004 |
| T ₇ | 22.33 | 65.88 | 93.40 | 98.12 | 231 | 300 | 357 | 339 | 64 | 492 | 697 | 958 |
| T ₈ | 22.09 | 67.02 | 94.12 | 100.13 | 236 | 309 | 361 | 348 | 75 | 503 | 710 | 1,000 |
| T ₉ | 25.06 | 67.18 | 95.41 | 100.20 | 240 | 308 | 365 | 353 | 78 | 506 | 716 | 1,009 |
| T ₁₀ | 22.84 | 66.20 | 93.55 | 98.57 | 233 | 304 | 359 | 343 | 69 | 496 | 707 | 985 |
| T ₁₁ | 23.12 | 67.66 | 95.42 | 100.47 | 243 | 310 | 366 | 352 | 76 | 514 | 724 | 1,028 |
| T ₁₂ | 25.91 | 68.01 | 95.53 | 100.53 | 245 | 313 | 368 | 354 | 80 | 520 | 733 | 1,035 |
| SEm± | 0.33 | 0.57 | 0.60 | 0.64 | 2.37 | 2.56 | 2.97 | 2.89 | 3 | 7 | 9 | 13 |
| CD (P=0.05) | 1.00 | 1.60 | 1.78 | 1.88 | 6.95 | 7.51 | 8.71 | 8.50 | 9 | 21 | 27 | 39 |

T₁, dry seed surface seeding with 100 kg/ha seed rate; T₂, dry seed surface seeding with 125 kg/ha seed rate; T₃, dry seed surface seeding with 150 kg/ha seed rate; T₄-12 hours soaked seed surface seeding with 100 kg/ha seed rate; T₅, 12 hours soaked seed surface seeding with 125 kg/ha seed rate; T₆, 12 hours soaked seed surface seeding with 150 kg/ha seed rate; T₇, seed priming with 1% KNO₃ at 100 kg/ha seed rate; T₈, seed priming with 1% KNO₃ at 125 kg/ha seed rate; T₉, seed priming with 1% KNO₃ at 150 kg/ha seed rate; T₁₀, seed priming with 1% CaCl₂ at 100 kg/ha seed rate; T₁₁, seed priming with 1% CaCl₂ at 125 kg/ha seed rate; T₁₂, seed priming with 1% CaCl₂ at 150 kg/ha seed rate

such as grain. Adoption of seed priming with 1% CaCl₂ at 150 kg/ha seed rate (T₁₂) showed highest dry matter accumulation of 80.45 g/m², 527 g/m², 733 g/m² and 1035 g/m² at 30, 60 90 DAS respectively (Table 2). Dry matter accumulation increased with increasing seed rate and with adoption of various priming techniques because of enhanced plant population, and chlorophyll content leading to more accumulation of photosynthates (Alhammad *et al.*, 2023).

The analysis of data revealed that the highest grain yield of 4.67 t/ha was reported in seed priming with 1% CaCl₂ at 150 kg/ha seed rate and the lowest (3.51 t/ha) in dry seed surface seeding at 100 kg/ha seed rate (Table 3). It was due to increased mortality of seedlings in dry seed surface seeding. An increase in seed rate and priming helps in maintaining the optimum plant population as well as the number of tillers resulting in increased yield. The treatment seed priming with 1% CaCl₂ at 150 kg/ha seed rate showed the high-

Table 3. Effect of different seed priming methods and seed rate on yield and economics of wheat

| Treatment | Grain yield (t/ha) | Straw yield (t/ha) | Harvest index | Gross returns (₹/ha) | Net returns (₹/ha) | Benefit: cost ratio |
|-----------------|--------------------|--------------------|---------------|----------------------|--------------------|---------------------|
| T ₁ | 3.54 | 4.45 | 44.05 | 87,715 | 53,198 | 2.51 |
| T ₂ | 3.82 | 4.79 | 44.40 | 94,676 | 59,109 | 2.66 |
| T ₃ | 4.10 | 4.38 | 43.50 | 98,495 | 61,878 | 2.68 |
| T ₄ | 3.80 | 4.36 | 45.06 | 93,634 | 59,117 | 2.71 |
| T ₅ | 3.93 | 4.83 | 44.53 | 97,234 | 61,667 | 2.73 |
| T ₆ | 4.32 | 5.27 | 45.05 | 106,325 | 69,708 | 2.90 |
| T ₇ | 4.01 | 5.16 | 43.74 | 99,897 | 64,490 | 2.82 |
| T ₈ | 4.46 | 5.52 | 44.71 | 110,288 | 73,608 | 3.00 |
| T ₉ | 4.50 | 5.59 | 44.59 | 111,271 | 73,319 | 2.93 |
| T ₁₀ | 4.11 | 4.99 | 45.15 | 101,219 | 65,802 | 2.85 |
| T ₁₁ | 4.60 | 5.68 | 44.78 | 113,661 | 76,969 | 3.09 |
| T ₁₂ | 4.67 | 5.69 | 45.02 | 114,851 | 76,884 | 3.02 |
| SEm± | 0.18 | 0.27 | 2.24 | 4,222 | 4,222 | 0.04 |
| CD (P=0.05) | 0.52 | 0.80 | NS | 12,382 | 12,382 | 0.14 |

T₁, dry seed surface seeding with 100 kg/ha seed rate; T₂, dry seed surface seeding with 125 kg/ha seed rate; T₃, dry seed surface seeding with 150 kg/ha seed rate; T₄, 12 hours soaked seed surface seeding with 100 kg/ha seed rate; T₅, 12 hours soaked seed surface seeding with 125 kg/ha seed rate; T₆, 12 hours soaked seed surface seeding with 150 kg/ha seed rate; T₇, seed priming with 1% KNO₃ at 100 kg/ha seed rate; T₈, seed priming with 1% KNO₃ at 125 kg/ha seed rate; T₉, seed priming with 1% KNO₃ at 150 kg/ha seed rate; T₁₀, seed priming with 1% CaCl₂ at 100 kg/ha seed rate; T₁₁, seed priming with 1% CaCl₂ at 125 kg/ha seed rate; T₁₂, seed priming with 1% CaCl₂ at 150 kg/ha seed rate

est straw yield (5.69 t/ha). Higher seed rate and priming techniques resulted in more dry matter accumulation per unit area and ultimately enhanced straw yield (Kubsad and Mansur, 2020). Different seed rates and priming techniques did not affect the harvest index significantly. The highest harvest index (45.15 %) was under seed priming with 1% CaCl₂ at 100 kg/ha seed rate (T₁₀), which was 3.81% higher compared to the lowest harvest index (43.50 %) obtained with dry seed surface seeding at 150 kg/ha seed rate. Harvest index mainly depends on crop species and cultivars. In this experiment, the cultivar was the same so there was no significant difference among different treatments (Elhag *et al.*, 2017).

Likewise, different economic parameters such as gross return, net return, and benefit-cost ratio (B: C ratio) are calculated for different treatments (different seed rates and priming techniques) for wheat growth, yield, and their attributes. Data presented in Table 3 clearly show that there was significant variation in gross return, net return, and benefit-cost ratio among different treatments. The highest gross return (₹114851/ha) and net return (₹76884/ha) were obtained under seed priming with 1% CaCl₂ at 150 kg/ha seed rate (T₁₂) because the highest grain and straw yield was obtained from the same treatment. The highest benefit-cost ratio 3.09 was obtained with T₁₁ as the cost of cultivation was less under T₁₁ ratio was higher under T₁₁. These results conform with Farooq *et al.* (2020) and Tikait *et al.* (2023).

Thus, it can be concluded that the seed priming with 1% CaCl₂ at 150 kg/ha seed rate is a viable option for sustainable wheat production.

REFERENCES

- Abdul-baki, B.A.A. and Anderson, J.D. 1973. Relationship between decarboxylation of glutamic acid and vigor in soybean seed. *Crop Science* **13**: 222–226.
- Abou-Zeid, H.M., Ismail, G.S.M. and Abdel-Latif, S.A. 2021. Influence of seed priming with ZnO nanoparticles on the salt-induced damages in wheat (*Triticum aestivum* L.) plants. *Journal of Plant Nutrition* **44**(5): 629–643. doi:10.1080/01904167.2020.1849288
- Alhammad, B.A., Roy, D.K., Ranjan, S., Padhan, S.R., Sow, S., Nath, D., Seleiman, M.F. and Gitari, H. 2023. Conservation tillage and weed management influencing weed dynamics, crop performance, soil properties, and profitability in a rice-wheat-green gram system in the Eastern Indo-Gangetic Plain. *Agronomy* **13**(7): 1953. doi:10.3390/agronomy13071953
- Ambreen, S., Athar, HuR., Khan, A., Zafar, Z.U., Ayyaz, A. and Kalaji, H.M. 2021. Seed priming with proline improved photosystem II efficiency and growth of wheat (*Triticum aestivum* L.). *BMC Plant Biology* **21**: 502. doi:10.1186/s12870-021-03273-2.
- Dayal, P., Kumar, A., Singh, M., Ranjan, S., Sow, S., Pal, R.K., Tyagi, S. and Jena, T. 2023. Soil fertility status and physiological performance of wheat grown under contrasting tillage and weed management scenarios. *Journal of Soil and Water Conservation* **22**(3): 242–249. doi:10.5958/2455-7145.2023.00031.0
- Directorate of Economics and Statistics, Ministry of Agriculture & Farmers Welfare, Government of India. 2022–23. Final estimates. <https://eands.da.gov.in/>.
- Elhag, D. 2017. Effect of different nitrogen rates on productivity and quality traits of wheat cultivars. *Egyptian Journal of Agronomy* 321–335. doi:10.21608/agro.2017.1405.1070.
- Farooq, M., Hussain, M., Habib, M.M., Khan, M.S., Ahmad, I., Farooq, S. and Siddique, K.H.M. 2020. Influence of seed priming techniques on grain yield and economic returns of bread wheat planted at different spacings. *Crop and Pasture Science* **71**(8): 725–738. doi:10.1071/CP20065
- Farooq, S., Hussain, M., Jabran, K., Hassan, W., Rizwan, M.S. and Yasir, T.A. 2017. Osmopriming with CaCl₂ improves wheat (*Triticum aestivum* L.) production under water-limited environments. *Environmental Science and Pollution Research* **24**(15): 13,638–13,649.
- Gomez, K.A. and A.A. Gomez. 1984. *Statistical procedures in agricultural research*. New York: Wiley.
- Iqbal, S., Khan A.M., Dishad, I., Moatter, K., Ahmed, T. and Gilani, S.A. 2020. Influence of seed priming with CuSO₄ and ZnSO₄ on germination and seedling growth of oat under NaCl stress. *Pure and Applied Biology* **9**(1): 897–912. doi:10.19045/bspab.2020.90094.
- Khaing, M., Ultra Jr., V.U. and Lee, S.C. 2020. Seed priming influence on growth, yield, and grain biochemical composition of two wheat cultivars. *Journal of Agricultural Science and Technology* **22**(3): 875–888.
- Kubsad, V.S. and Mansur, C.P. 2020. Effect of seed priming practices on yield and economics of winter (*Rabi*) sorghum (*Sorghum bicolor*). *Indian Journal of Agronomy* **65**(4): 462–464.
- Paswan, A., Kumar, N. and Sow, S. 2023. Impact of different crop establishment techniques on growth and yield of drought tolerant rice varieties. *Journal of Cereal Research* **15**(2): 304–308. doi:10.25174/2582-2675/2023/131022
- Sharma, J., Sharma, B.C., Puniya, R., Kumar, A., Mahajan, A. and Kumar, R. 2022. Effect of seed priming and plant geometry on productivity and profitability of wheat (*Triticum aestivum*) in the modified system of wheat intensification under subtropical conditions of Jammu. *Indian Journal of Agronomy* **67**(3): 247–251. doi:10.59797/ija.v67i3.14
- Sharma, V., Kharb, V., Verma, V., Dhaliwal, S.S., Kalia, A., Behera, S.K. and Singh, P. 2024. Comparative potential of different Fe sources for seed priming to enhance yield and iron content in direct seeded aerobic rice. *Cereal Research Communications*. doi:10.1007/s42976-024-00503-9
- Sheteiw, M.S., Dong, Q., An, J., Song, W., Yajing, G., He, F., Huang, Y. and Hu, J. 2017. Regulation of ZnO nanoparticles-induced physiological and molecular changes by seed priming with humic acid in *Oryza sativa* seedlings. *Plant Growth Regulation* **83**(1): 27–41. doi:10.1007/s10725-017-0281-4.
- Singh, H., Jha, G., Babu, S. and Jha, A.K. 2013. Effect of seed rate and sowing depth on growth, yield attributes, and yield of irrigated wheat (*Triticum aestivum*) in Madhya Pradesh. *Indian Journal of Agronomy* **58**(2): 259–61.
- Sneha, G.R., Govindasamy, V., Singh, P.K., Kumar, S. and Abraham, G. 2024. Priming of seeds with cyanobacteria improved

- tolerance in wheat (*Triticum aestivum* L.) during post-germinative drought stress. *Journal of Applied Phycology* **36**: 1233–1246. doi:10.1007/s10811-023-03170-1
- Sow, S., Singh, G., Ghosh, M., Dutta, S.K., Mandal, N., Kumar, S. and Ranjan, S. 2023. Nitrogen-management strategy through leaf-colour chart and SPAD meter for optimizing the productivity in irrigated wheat (*Triticum aestivum*). *Indian Journal of Agronomy* **68**(2): 219–222. doi: 10.59797/ija.v68i2.364
- Tikait, S., Saini, K.S., Kaur, J. and Kaur, P. 2023. Influence of seed rate and foliar nitrogen on productivity and profitability of wheat (*Triticum aestivum*) in green manure basmati rice (*Oryza sativa*) wheat cropping system. *Indian Journal of Agronomy* **68**(4): 439–442: doi:10.59797/ija.v68i4.5469

Efficacy of various herbicides for weed management in irrigated chickpea (*Cicer arietinum*)

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ABSTRACT

Chickpea is a short-stature crop with slow initial growth and limited leaf area development due to which it is heavily infested with a wide spectrum of weeds. The menace of weeds has increased to such an extent that an effective weed management schedule has become a necessity. A research study was conducted during the *rabi* season of 2021–22 at the Agronomy Research Farm, Chaudhary Charan Singh Haryana Agricultural University, Hisar, Haryana. Thirteen weed control treatments *viz.*, pre-plant incorporation (PPI) and pre-emergence (PRE) pendimethalin at 1,000 g/ha, PPI imazethapyr at 75 g/ha and 100 g/ha, PRE imazethapyr at 75 g/ha and 100 g/ha, post-emergence (PoE) imazethapyr at 75 g/ha and 100 g/ha, PPI and PRE pendimethalin + imazethapyr Ready mix (RM) at 1,000 g/h and two hand hoeings at 30 and 50 DAS were compared with weedy check and weed free in a randomized block design and replicated thrice. Among the herbicides, lowest weed dry weight was observed under PPI and PRE pendimethalin + imazethapyr (RM) at 1,000 g/ha respectively. PoE application of imazethapyr displayed phytotoxicity symptoms like stunting, leaf crinkling, and chlorosis as indicated by phytotoxicity scale ranging from 1-5. Significantly higher seed yield was obtained by pendimethalin + imazethapyr (1,827 kg/ha) over other combinations. Therefore, the PRE-application of pendimethalin + imazethapyr (RM) at 1,000 g/ha was the most suitable herbicide for efficient weed management in chickpea as it not only controlled the diverse weed flora but also improved seed yield.

Key words: Chickpea, Imazethapyr, Pendimethalin, Phytotoxicity, Weed control efficiency

Chickpea (*Cicer arietinum* L.) is a self-pollinating legume crop classified under the family Leguminosae. The average chickpea yield in India stands at around 11.9 million tons, grown over 8.8 million hectares with a national productivity rate of 1.11 tons/hectare (Anonymous, 2022). India holds the distinction of being both the lead producer and consumer of chickpea globally. Despite the cultivation of high-yielding varieties and the adoption of improved agronomic practices, chickpea productivity remains low. One contributing factor is the prevalence of weeds in chickpea fields. Chickpea exhibits slow growth and limited leaf area development in the early stages, making it a weak competitor against weeds. During the *rabi* season, broadleaf weeds

are particularly detrimental to yield compared to grassy weeds (Baghel, 2018). The major weeds in chickpea are *Chenopodium album*, *Fumaria parviflora* and *Phalaris minor* and other minor weed species are *Convolvulus arvensis*, *Anagallis arvensis*, *Melilotus alba*, *Coronopus didymus* and *Spergula arvensis* (Khope *et al.*, 2011). Hand weeding and mechanical weed control methods traditionally followed in developing countries like India are becoming expensive due to increased labour wages. The pre-emergence herbicides effectively control weeds at the early stage of seedling growth, but weeds germinating after crop emergence become dominant in the field and cause substantial yield losses. Gupta *et al.* (2017) reported that among the chemical herbicides, PRE application of pendimethalin 30% EC + imazethapyr 2% EC (RM) recorded the highest net monetary returns (₹20,208 /ha) and B:C ratio (2.0). Kumar and Sharma (2022) reported weed control efficiency of 76.2% under application of pendimethalin @ 1 kg/ha which proves that pendimethalin had a pronounced effect on weed density. In view of this, the present study was planned to study the effect of pendimethalin, imazethapyr, and its RM formulation at various doses and time of application to find out the best

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dose of herbicide for getting higher weed control efficiency and yield of irrigated chickpea.

The experiment was conducted at the Agronomy Research Farm, Chaudhary Charan Singh Haryana Agricultural University, Hisar, during the *rabi* season of 2021–22. Meteorological data for this season was consistently recorded at the CCSHAU Research Farm's meteorological observatory. The experimental site, situated at 29° 10' N latitude and 75° 46' E longitude in Haryana State, India, has an elevation of 215.2 m above mean sea level. Hisar experiences a semi-arid, sub-tropical climate with hot, dry summers and intense cold winters. The range of maximum and minimum temperature varied between 14.0–41.1 °C and 3.3–21.2 °C, respectively. The total rainfall received during the crop growing period was 72.9 mm. The mean weekly values for morning and evening relative humidity ranged between 68 to 99 and 17 to 79%, respectively. The bright sunshine during crop growth period ranged between 0.7 and 8.8 hours. Availability of favourable temperature and solar radiation proved conducive for growth and yield attributing characters and eventually to the higher yield. The total pan evaporation was 67.8 mm during 2021–22.

The soil in the experimental area is sandy loam, with organic carbon content of 0.5%, available nitrogen at 113 kg/ha, available phosphorus at 11.7 kg/ha, available potassium at 252 kg/ha, and a pH of 8.1. The experiment was laid out in a randomized block design with 13 treatments replicated thrice. The allocation of treatments in the field was random, with the chickpea variety HC-6 planted in plots measuring 5 m in length and 4.5 m in width. The treatments involved various herbicides and weed control measures. The details of treatments are as follows: T₁ (pendimethalin 30EC @ 1,000 g/ha applied as pre-plant incorporation), T₂ (imazethapyr 10EC @ 75 g/ha applied as pre-plant incorporation), T₃ (imazethapyr 10EC @ 100 g/ha applied as pre-plant incorporation), T₄ (pendimethalin 30EC + imazethapyr 2% EC (ready mix RM) @ 1,000 g/ha applied as pre-plant incorporation), T₅ (pendimethalin 30EC @ 1,000 g/ha applied as pre-emergence), T₆ (imazethapyr 10EC @ 75 g/ha applied as pre-emergence), T₇ (imazethapyr 10EC @ 100 g/ha applied as pre-emergence), T₈ (pendimethalin 30EC + imazethapyr 2EC (RM) @ 1,000 g/ha applied as pre-emergence), T₉ (imazethapyr 10EC @ 75 g/ha applied as post-emergence), T₁₀ (imazethapyr 10EC @ 100 g/ha applied as post-emergence), T₁₁ (two hand hoeing at 30 & 50 DAS), T₁₂ (weed-free), and T₁₃ (weedy check). The field was prepared with the help of a tractor-drawn cultivator to break up clods and residues from the previous crop were cleared. Cross harrowing and two additional cultivator passes were followed by planking, creating finely tilled soil for sowing. As part of field preparation, a standardized basal dose of fertilizers

(20 kg/ha nitrogen and 40 kg/ha phosphorous through DAP) was applied. Following the planned layout, the crop was sown using the *pora* method on October 30, 2021. Herbicides were applied with a knapsack sprayer, ensuring sufficient soil moisture during application. The treatment plot (T₁₂) was kept weed-free through manual hand weeding throughout the crop growing period. Two hoeing at 30 and 50 days after sowing (DAS) in T₁₁ were performed using a hand hoe, maintaining recommended spacing and a weed-free environment. The experimental area experienced no severe instances of insect pests or diseases, and the plant stand remained satisfactory, eliminating the need for additional plant protection measures. At full physiological maturity, the chickpea crop was harvested using a sickle, cutting close to the ground in each plot separately. The harvested produce was sun-dried in the respective plot until a constant weight was achieved. After drying, bundles of produce were formed for each plot, and their weights were recorded. Subsequently, the crop was hand-threshed, and the seed weight of each plot was measured in kg/plot and later calculated to kg/ha. The dry mass accumulation of weeds was documented at 60, 90, 120 DAS and at harvest. Weeds within a 0.25 m² quadrat were removed, and their roots were separated, air-dried, and subsequently oven-dried at 60°C for 48 hours and the dry weight was recorded. Phytotoxicity of herbicides was recorded at all crop growth stages. Phytotoxicity was graded in the scale of 1–5 (Punia *et al.*, 2015). The weed control efficiency (WCE) was determined at 60, 90, 120 DAS and at harvest by assessing the decrease in weed dry matter production in treated plots relative to the weedy check as per the given formula (Patil and Patil, 1983).

$$\text{WCE (\%)} = \frac{\text{Weed dry matter in weedy check} - \text{Weed dry matter treated plot}}{\text{Weed dry matter in weedy check}} \times 100$$

The data exhibited significant variability in both weed count and weed dry weight. To attain the assumption of the analysis of variance, the data for weed count and weed dry weight underwent square root transformation using the formula $\sqrt{x + 0.5}$, as recommended by Chandel and Yadava (1984). The data collected on various weed parameters were statistically analysed with ANOVA using standard Randomised Block Design and post-hoc test for grain yield (Gomez and Gomez, 1984).

The experimental field was mainly dominated by dicot weeds (*Chenopodium album*, *Fumaria parviflora*, *Anagallis arvensis*). The other weeds infesting the crop comprised of *Convolvulus arvensis*, *Melilotus alba*, *Coronopus didymus*, *Spergula arvensis* and *Phalaris minor*. Among the different herbicides, imazethapyr showed phytotoxicity when applied as PoE @ 75 g/ha and 100 g/ha, respectively. The phytotoxicity was in the form of

Table 1. Effect of weed control treatments on WCE (%), dry weight of weeds (g/m²) and phytotoxicity

| Treatment | WCE (%) | | | | | | Dry weight of weeds (g/m ²) | | | | | | Phytotoxicity scale (1–5 scale) | | | | | | | | | | | | |
|-----------------|---------|--------|--------|--------|---------|---------|---|---------|--------|------|--------|------|---------------------------------|---|----------|---|--------|---|--------|---|---------|---|----------|---|--|
| | 60 DAS | | 90 DAS | | 120 DAS | | Maturity | | 60 DAS | | 90 DAS | | 120 DAS | | Maturity | | 60 DAS | | 90 DAS | | 120 DAS | | Maturity | | |
| | DAS | | DAS | | DAS | | DAS | | DAS | | DAS | | DAS | | DAS | | DAS | | DAS | | DAS | | DAS | | |
| T ₁ | 61.40 | 53.56 | 55.75 | 51.42 | 3.05 | 3.56 | 4.10 | 4.45 | 3.05 | 3.56 | 4.10 | 4.45 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | |
| T ₂ | 37.88 | 27.68 | 40.04 | 37.53 | (8.30) | (11.69) | (15.78) | (18.78) | 3.79 | 4.38 | 4.73 | 5.02 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | |
| T ₃ | 46.22 | 32.72 | 45.21 | 42.10 | (13.36) | (18.20) | (21.39) | (24.16) | 3.54 | 4.24 | 4.53 | 4.84 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | |
| T ₄ | 69.75 | 66.08 | 61.61 | 56.83 | (11.56) | (16.93) | (19.54) | (22.39) | 2.74 | 3.09 | 3.83 | 4.21 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | |
| T ₅ | 61.12 | 52.58 | 56.38 | 52.01 | (6.50) | (8.54) | (13.69) | (16.69) | 3.06 | 3.60 | 4.07 | 4.42 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | |
| T ₆ | 39.85 | 27.81 | 39.53 | 36.39 | (8.36) | (11.93) | (15.56) | (18.56) | 3.73 | 4.38 | 4.75 | 5.06 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | |
| T ₇ | 45.73 | 33.89 | 44.92 | 43.05 | (12.93) | (18.17) | (21.57) | (24.60) | 3.56 | 4.20 | 4.54 | 4.80 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | |
| T ₈ | 70.31 | 64.77 | 61.68 | 56.90 | (11.67) | (16.64) | (19.64) | (22.02) | 2.71 | 3.14 | 3.83 | 4.20 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | |
| T ₉ | 52.09 | 36.86 | 49.82 | 46.53 | (6.38) | (8.87) | (13.67) | (16.67) | 3.35 | 4.11 | 4.35 | 4.66 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | |
| T ₁₀ | 53.18 | 38.15 | 51.53 | 47.43 | (10.30) | (15.89) | (17.90) | (20.68) | 3.33 | 4.07 | 4.28 | 4.62 | 2 | 4 | 4 | 4 | 2 | 4 | 4 | 4 | 2 | 4 | 4 | 3 | |
| T ₁₁ | 90.85 | 86.36 | 80.28 | 76.81 | (10.07) | (15.57) | (17.29) | (20.33) | 1.72 | 2.10 | 2.83 | 3.16 | 2 | 4 | 4 | 2 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | |
| T ₁₂ | 100.00 | 100.00 | 100.00 | 100.00 | (1.97) | (3.43) | (7.03) | (8.97) | 1.00 | 1.00 | 1.00 | 1.00 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | |
| T ₁₃ | 0.00 | 0.00 | 0.00 | 0.00 | (0.00) | (0.00) | (0.00) | (0.00) | 4.74 | 5.12 | 6.05 | 6.30 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | |
| SEm± | | | | | 0.05 | 0.04 | 0.04 | 0.03 | | | | | | | | | | | | | | | | | |
| CD (P=0.05) | | | | | 0.13 | 0.12 | 0.13 | 0.10 | | | | | | | | | | | | | | | | | |

*T₁, (pendimethalin 30 EC @ 1,000 g/ha applied as pre-plant incorporation), T₂, (imazethapyr 10 EC @ 75 g/ha applied as pre-plant incorporation), T₃, (imazethapyr 10 EC @ 100 g/ha applied as pre-plant incorporation), T₄, (pendimethalin 30 EC + imazethapyr 2% EC (ready mix RM) @ 1,000 g/ha applied as pre-plant incorporation), T₅, (pendimethalin 30 EC @ 1,000 g/ha applied as pre-emergence), T₆, (imazethapyr 10 EC @ 75 g/ha applied as pre-emergence), T₇, (imazethapyr 10 EC @ 100 g/ha applied as pre-emergence), T₈, (pendimethalin 30 EC + imazethapyr 2 EC (RM) @ 1,000 g/ha applied as pre-emergence), T₉, (imazethapyr 10 EC @ 75 g/ha applied as post-emergence), T₁₀, (imazethapyr 10 EC @ 100 g/ha applied as post-emergence), T₁₁, (2 hand hoeing at 30 and 50 DAS); T₁₂, (weed-free), and T₁₃, (weedy check)

#Phytotoxicity scale: 1, 0–20%; 2, 21–40%; 3, 41–60%; 4, 61–80%; 5, 81–100% phytotoxicity.

Figures in the parenthesis indicate mean of original values.

stunted growth, bushy plant, chlorosis, necrosis, and reduced leaf size of chickpea plants. As the crop growth advanced and approached maturity, the plants recovered but to a very little extent. Total weed dry weight at 60 DAS, 90 DAS, 120 DAS and at maturity is presented in Table 1. Amongst the herbicidal treatments, the total weed dry weight was the lowest under PPI and PRE application of pendimethalin + imazethapyr (RM) @ 1,000 g/ha and statistically at par with each other (Table 1). WCE was significantly affected by weed control treatments in chickpea. WCE of a treatment has strong negative correlation with weed biomass. Maximum weed control efficiency (%) at 60, 90, 120 DAS, and at maturity was recorded with two hoeing performed at 30 and 50 DAS (86.76, 90.85, 86.36, 80.28 and 76.81%, respectively). Among the herbicidal treatments, highest weed control efficiency was recorded at 60, 90, 120 DAS and at maturity with PRE application of pendimethalin + imazethapyr (RM) @ 1,000 g/ha 70.31, 64.77, 61.68 and 56.90%, respectively. Two hand hoeing at 30 and 50 DAS produced significantly lower dry matter as compared to different herbicide treatments and weedy check. This might be due to the reduced weed intensity of one or the other weeds in different weed control treatment. Unchecked growth of weeds in weedy check resulted in 55.2% reduction in seed yield, compared to weed free plots (Figure 1). Maximum seed yield (1,968 kg/ha) and higher value of yield attributes of chickpea were recorded with weed free treatment which were statistically at par with two hand hoeing performed at 30 and 50 DAS (1,940 kg/ha) and among herbicidal treatments, maximum seed yield was recorded with PRE application of pendimethalin + imazethapyr (RM) @ 1,000 g/ha (1,827 kg/ha) which was significantly higher over pendimethalin 30EC @ 1,000 g/ha applied as pre-emergence, imazethapyr 10EC @100 g/

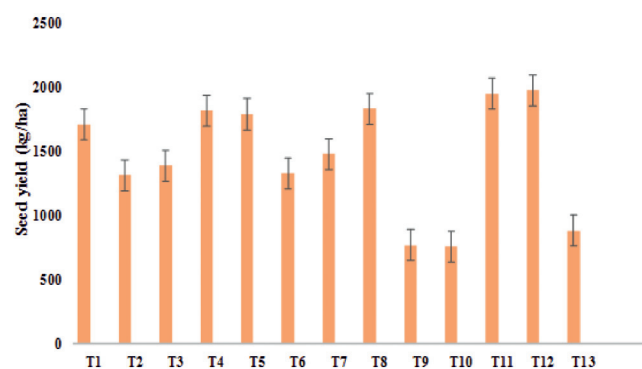


Fig. 1. Effect of weed control treatments on chickpea seed yield

ha applied as pre-emergence, imazethapyr 10EC @ 75 g/ha applied as pre-emergence by 2.35, 19.27, and 27.59 %, respectively. Sahu *et al.* (2023) also reported hand weeding at 30 DAS led to lowest number of weeds with lesser weed biomass resulting in higher weed control efficiency (WCE).

From this study, this can conclude that PPI or PRE application of pendimethalin + imazethapyr (RM) @ 1,000 g/ha is the best option to control dicot weeds in chickpea followed by PRE application of pendimethalin @ 1,000 g ha⁻¹. Post emergence application of imazethapyr at a high dose (75 and 100 g/ha) should be completely avoided to reduce the phytotoxicity to a minimum. Ready mix is highly desirable as its PRE application not only controlled the weed flora but also recorded seed yield of 1,827 kg/ha.

REFERENCES

- Anonymous. 2022. Agricultural Statistics at a Glance, Directorate of Economics and Statistics, Ministry of Agriculture and Farmers Welfare, Government of India.
- Baghel, R. 2018. Bio-efficacy of pendimethalin (38.7% CS) as PPI against complex weed flora in Chickpea. Thesis M.Sc., Jawaharlal Nehru Krishi Vishwavidyalaya, Jabalpur, Madhya Pradesh.
- Chandel, R.C.S. and Yadava, H.C. 1984. Heat-conduction and the multiple hypergeometric function of srivastava and daoust. *Indian Journal of Pure and Applied Mathematics* **15**(4): 371–376.
- Gomez, K.A. and Gomez, A.A. 1984. Statistical procedures for agricultural research. John Wiley & Sons.
- Gupta, K.C., Vipen, K. and Saxena, R. 2017. Efficacy of weed control practices on weed dynamics, yield and economics of chickpea (*Cicer arietinum* L.). *Plant Archives* **17**(1): 258–260.
- Khope, D., Kumar, S. and Pannu, R.K. 2011. Evaluation of post-emergence herbicides in chickpea (*Cicer arietinum*). *Indian Journal of Weed Science* **43**: 92–93
- Kumar, T.M.N., and Sharma, A.R. 2022. Effect of tillage and herbicides on growth, weed control and energetics of chickpea (*Cicer arietinum*) grown in sequence with sorghum (*Sorghum bicolor*). *Indian Journal of Agronomy* **67**(3): 320–323.
- Patil, V.C. and Patil, S.V. 1983. Studies on weed control in bamboo. *Indian Journal of Weed Science* **15**(1): 83–86.
- Punia, S.S., Yadav, D., Duhan, A. and Mohammad Irfan. 2015. Bio-efficacy and phytotoxicity of herbicides in green gram and their residual effect on succeeding mustard. *Indian Journal of Weed Science* **47**(4): 386–489.
- Sahu, M.P., Kewat, M.L., Jha, A.K., Choudhary, V.K., Verma, B., Patidar, J., Singh, V. and Sanodiya, P. 2023. Effect of crop residue and weed management on weed incidence, soil moisture and yield of chickpea. *Indian Journal of Agronomy* **68**(4): 404–412.

Optimizing nutrient management for sustaining sugarcane yield through integration of biochar, digested sludge, liquid slurry and ash applications with inorganic fertilizers

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ABSTRACT

A field experiment was laid out during 2023–24 at ICAR-Indian Agricultural Research Institute, New Delhi to study the effect of various nutrient management options on growth performance, yield and quality of sugarcane. The sixteen treatments comprised of organics (biochar, solid digestate, ash and liquid slurry) and inorganic (synthetic fertilizers) sources in integrated form were evaluated in randomized block design with three replications. The result revealed that a significantly higher plant height (407.8 cm), number of tillers ($191 \times 10^3/\text{ha}$), leaf area (51,169 cm²), leaf-area index (6.81) and cane yield (91.2 t/ha) of sugarcane were obtained with the integration of 100% synthetic along with 4 t/ha solid digest, which was at par to 100% NP + K through liquid digest, 100% synthetic + 6 t/ha biochar and 100% NP + K through Ash, while the lowest were observed under treatment receiving organic manure alone i.e. 100% N through solid digestate, might be owing to very slow mineralization process of nutrients. The former treatments (combination of organic and inorganic nutrient sources) also resulted in better sugarcane quality in terms of increased °brix reading.

Key words: Ash, Biochar, Brix, Liquid digest, Solid digestate

Sugarcane (*Saccharum officinarum* L.) is a crop of global significance, valued for its role in sugar production and increasingly recognized for its potential in bioenergy generation. In India, the area, production and productivity of sugarcane remained at 5.15 Mha, 431.81 MT and 8.31 t/ha respectively (Anonymous, 2022). There exists further scope to enhance sugarcane productivity by proper nutrient management. As sugarcane is a highly nutrient-demanding crop, therefore efficient nutrient management is crucial for maximizing yield and quality while minimizing environmental footprint. This involves the strategic application of fertilizers, recycling of nutrients through organic amendments, and the adoption of precision agriculture techniques to optimize nutrient use efficiency (NUE). Advances in understanding the complex nutrient dynamics in sugarcane systems, including the role of soil microbiota and the impact of climate variability, are critical for developing sustainable nutrient management practices that support both

agricultural productivity and environmental sustainability. The application of balanced N, P and K along with other essential nutrients, is key for increasing sugarcane yield and sugar content. However, the current large-scale application of N fertilizer in sugarcane production has caused problems such as low fertilizer utilization, soil acidification, compaction, toxin accumulation, and reduced fertility (Rathore *et al.*, 2021). Integration of organic sources of the nutrients with available inorganic fertilizers in different combinations will be helpful for a balanced nutrient supply to sugarcane crop. In this regard, the secondary product of the anaerobic digestion, like the slurry, biogas digestate, or simply digestate are good options. The solid digestate contains organic compounds of both plant and microbial origin and numerous mineral elements. The N in slurry ranges from 1.2 to 9.0 kg/Mg fresh weight (FW), and phosphorus from 0.4 to 2.6 kg/Mg FW. Restoring soil fertility in Indian soils under intensive agro-ecologies is a major challenge due to limited availability of organic nutrient sources. The emerging multi-nutrient deficiencies with the use of high analysis fertilizers leads to depletion in soil organic carbon and are mainly responsible for plateauing yield (Mahapatra *et al.*, 2001). The carbon rich porous and large surface area

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characteristics of biochar aid in moisture absorption and entrapping contaminants and, as a soil conditioner, reduce GHG emissions, and increase soil nutrient availability, which improves plant growth and ultimately enhances farm productivity. Also, biochars and feedstock materials were chemically characterized for their nutrient content and several physico-chemical properties (Lima and White, 2017). Similarly, the biogas slurry is leftover slurry produced by anaerobic breakdown of biogas source substrates like animal manure or plant debris. Biogas slurry has attracted much interest because of its potential contribution to recovering soil characteristics and enhancing environmentally friendly agricultural productivity (Mukhtiar *et al.*, 2024). Ash, the residue from the combustion of organic materials, contains inorganic nutrients that can be beneficial to soil fertility when applied at appropriate rates. However, its impact on soil properties and crop productivity can vary widely depending on the feedstock and combustion conditions. Therefore, liquid slurry, solid digest and ash were tested in integration of inorganic fertilizers to quantify the impact on sugarcane yield, quality etc. under semi-arid conditions.

An experiment was conducted during the year 2023–24 at ICAR- Indian Agricultural Research Institute, Pusa, New Delhi situated at 28°37'46.2" N latitude, 77°09'43.8" E longitude, and altitude of 228.6 m above mean sea level. The experimental soil belongs to the order *Inceptisols*, clayey loam in texture, slightly basic in reaction (7.25 to 7.65), medium in organic carbon (0.55 to 0.60%), and low in available nitrogen (112.9 to 129.6 kg/ha), medium in available phosphorus (12.6 to 15.7 kg/ha) and available potassium (187.7 to 201.4 kg/ha). The experiment was laid out in randomized block design with three replications. The study comprised of 16 treatments *i.e.*, 100% synthetic, 100% synthetic + 25% biochar (w/w), 100% synthetic + 25% solid digestate (SD) (w/w), 100% synthetic + 4 t/ha SD, 100% synthetic + 6 t/ha biochar, 100% N through SD, 75% synthetic + 25% biochar (Target N), 75% synthetic + 25% SD (Target N), 75% synthetic + 25% biochar (w/w), 75% synthetic + 25% SD (w/w), 75% synthetic + 25% SD (Target N) + 25 kg/ha S, 75% synthetic + 25% biochar (Target N) + 25 kg/ha S, 75% synthetic + 25% biochar (70% of Target N), 75% synthetic + 25% SD (70% of Target N), 100% NP + K through ash and 100% NP + K through liquid slurry. Sugarcane variety 'Co-0238' was sown manually in the first week of May, 2023, using 40 q/ha seeds in rows of 75 cm apart. A recommended dose nitrogen (180 kg/ha), phosphorus (100 kg/ha), potassium (60 kg/ha) was adopted and supplemented by the organic manures according to the treatments. Half a dose of N and a full dose of P and K were applied as basal, while half of N was given as top-dressing at 120 days after planting (DAP).

The statistical analysis of the data was done according to the procedure given by Gomez and Gomez (1984).

The data regarding growth attributes *viz.*, plant height, number of tillers, leaf area and LAI (Table 1) indicate that the integration of bio-char, solid digest, liquid slurry and ash with recommended doses of fertilizers significantly influenced the growth parameters. Significantly taller plants were observed under treatment 100% synthetic + 4 t/ha SD. Data pertaining to number of tillers/ha reveal that at 120, 150 and 180 DAP, treatment, 100% synthetic + 4 t/ha SD was significantly superior over other treatments. The superior performance of treatment integrated with inorganic fertilizer and digested sludge regarding sugarcane growth can be attributed to the balanced and enhanced nutrient supply from both synthetic fertilizers and the solid digest, promoting optimal plant growth. The similar outcomes in treatments with integration of amendments like liquid slurry, biochar and ash along with synthetic fertilizers indicate that organic amendments effectively complement fertilizers by improving nutrient availability, water retention and soil health, leading to vigorous plant growth and tiller production. This result clearly corroborates the opinion of high fertilizer value of digestate, as a replacement for mineral fertilizers applied to crop (Przygocka-Cyna and Grzebisz, 2018). Previous studies have found that biochar can improve the root characteristics of the sugarcane seedlings and increase their root-shoot ratio (Liu *et al.*, 2015, Saurabh *et al.*, 2023).

Cane yield was significantly higher (91.2 t/ha) under 100% synthetic + 4 t/ha SD as compared to other treatments except treatment such as, 100% NP + K through liquid slurry, 100% synthetic + 6 t/ha biochar and 100% NP + K through ash. The lowest yield was recorded under treatment, 100% N through SD (Table 1). The solid digest might have helped in ensuring better nutrient supply to sugarcane crop in synchrony to the nutrient demand. Also, along with nutrient build up, the soil will also develop better resilience and overall better soil health will be resulted under use of these organic sources of nutrients (Przygocka-Cyna and Grzebisz, 2018, Babu *et al.*, 2023). Similarly, Gudade *et al.* (2023) and Verma *et al.* (2023) showed that various biochars significantly increased maize yields in sandy soils and partially reclaimed sodic soils, respectively. The brix reading was varied to range between 18.4 to 22.2, with non-significant variation among treatments (Table 1). However, treatment, 100% synthetic + 4 t/ha SD gave higher °brix value followed by 100% NP + K through liquid digest and 100% synthetic + 6 t/ha biochar. The higher brix value in above treatments is due to their rapid uptake and assimilation, enhancing photosynthesis and sugar synthesis. The study observed a strong positive correlation between cane yield and sugarcane leaf area ($r=0.94^{**}$) and

Table 1. Effect of biochar, solid digest, liquid slurry and ash in combination with inorganic fertilizers on sugarcane growth, yield and brix value

| Treatment | Plant height (cm) | | | | | | Number of tillers ($\times 10^3/\text{ha}$) | | | | | | Leaf area ($\text{cm}^2/\text{m row}$) | | | | | | Leaf area index | | | | Cane yield (t/ha) | $^{\circ}\text{Brix}$ | | |
|---|-------------------|-------|-------|-------|-----|-----|---|---------|---------|---------|---------|------|--|------|---------------|------|------|-----|-----------------|-----|-----|-----|-------------------|-----------------------|---------------|-----|
| | 120 | | 180 | | 240 | | At harvesting | | 120 | | 180 | | 240 | | At harvesting | | 120 | | 180 | | 240 | | | | At harvesting | |
| | DAP | DAP | DAP | DAP | DAP | DAP | DAP | DAP | DAP | DAP | DAP | DAP | DAP | DAP | DAP | DAP | DAP | DAP | DAP | DAP | DAP | DAP | | | DAP | DAP |
| 100% synthetic | 302.2 | 372.3 | 374.4 | 380.2 | 178 | 191 | 178 | 32,110 | 56,251 | 49,465 | 30,684 | 4.27 | 7.48 | 6.58 | 4.08 | 84.0 | 21.0 | | | | | | | | | |
| 100% synthetic + 25% biochar (w/w) | 303.2 | 373.1 | 379.9 | 382.0 | 178 | 191 | 178 | 33,478 | 57,881 | 50,561 | 29,108 | 4.45 | 7.70 | 6.72 | 3.87 | 84.6 | 21.0 | | | | | | | | | |
| 100% synthetic + 25% SD (w/w) | 307.8 | 389.7 | 393.7 | 394.0 | 182 | 196 | 182 | 34,829 | 62,238 | 52,505 | 40,810 | 4.63 | 8.28 | 6.98 | 5.43 | 85.2 | 21.8 | | | | | | | | | |
| 100% synthetic + 4 t/ha SD | 309.6 | 398.7 | 407.8 | 408.9 | 191 | 209 | 191 | 42,532 | 67,947 | 64,118 | 51,169 | 5.66 | 9.04 | 8.53 | 6.81 | 91.2 | 22.8 | | | | | | | | | |
| 100% synthetic + 6 t/ha biochar | 306.7 | 391.7 | 396.2 | 396.0 | 187 | 204 | 187 | 36,686 | 65,144 | 55,273 | 48,742 | 4.88 | 8.66 | 7.35 | 6.48 | 87.9 | 22.2 | | | | | | | | | |
| 100% N through SD | 286.0 | 330.2 | 333.5 | 338.7 | 156 | 169 | 147 | 23,128 | 33,305 | 26,608 | 19,614 | 3.08 | 4.43 | 3.54 | 2.61 | 76.7 | 18.4 | | | | | | | | | |
| 75% synthetic + 25% biochar (Target N) | 291.4 | 342.0 | 345.0 | 346.4 | 164 | 173 | 156 | 25,157 | 38,655 | 31,118 | 25,470 | 3.35 | 5.14 | 4.14 | 3.39 | 78.3 | 19.6 | | | | | | | | | |
| 75% synthetic + 25% SD (Target N) | 293.0 | 342.2 | 347.4 | 349.0 | 164 | 178 | 160 | 25,934 | 41,885 | 34,399 | 27,616 | 3.45 | 5.57 | 4.58 | 3.67 | 79.2 | 19.8 | | | | | | | | | |
| 75% synthetic + 25% biochar (w/w) | 299.6 | 348.0 | 352.5 | 360.2 | 173 | 191 | 169 | 29,581 | 48,738 | 44,232 | 33,671 | 3.93 | 6.48 | 5.88 | 4.48 | 82.6 | 20.3 | | | | | | | | | |
| 75% synthetic + 25% SD (w/w) | 299.6 | 360.1 | 365.4 | 367.2 | 178 | 191 | 169 | 30,905 | 51,393 | 45,217 | 33,835 | 4.11 | 6.84 | 6.01 | 4.50 | 83.1 | 20.7 | | | | | | | | | |
| 75% synthetic + 25% SD (Target N) + 25 kg/ha S | 300.3 | 367.1 | 371.3 | 372.5 | 169 | 191 | 178 | 29,911 | 54,810 | 49,226 | 36,353 | 3.98 | 7.29 | 6.55 | 4.84 | 83.4 | 20.9 | | | | | | | | | |
| 75% synthetic + 25% biochar (Target N) + 25 kg/ha S | 300.3 | 370.2 | 372.5 | 378.4 | 178 | 191 | 178 | 31,360 | 56,294 | 49,360 | 37,311 | 4.17 | 7.49 | 6.56 | 4.96 | 83.9 | 20.9 | | | | | | | | | |
| 75% synthetic + 25% biochar (70% of Target N) | 296.2 | 346.1 | 350.4 | 357.2 | 169 | 182 | 164 | 28,208 | 45,047 | 35,480 | 30,138 | 3.75 | 5.99 | 4.72 | 4.01 | 79.6 | 20.0 | | | | | | | | | |
| 75% synthetic + 25% SD (70% of Target N) | 296.7 | 347.0 | 351.7 | 358.7 | 169 | 182 | 169 | 28,455 | 48,238 | 42,669 | 33,304 | 3.78 | 6.42 | 5.67 | 4.43 | 81.9 | 20.0 | | | | | | | | | |
| 100% NP + K through Ash | 304.9 | 390.1 | 395.5 | 395.6 | 187 | 200 | 182 | 36,263 | 62,457 | 53,753 | 42,109 | 4.82 | 8.31 | 7.15 | 5.60 | 86.7 | 22.0 | | | | | | | | | |
| 100% NP + K through liquid digest | 308.6 | 394.3 | 399.4 | 407.5 | 191 | 204 | 187 | 38,034 | 65,714 | 60,770 | 49,038 | 5.06 | 8.74 | 8.08 | 6.52 | 90.1 | 22.7 | | | | | | | | | |
| CD (P=0.05) | NS | 23.7 | 27.4 | 27.6 | 13 | 16 | 13 | 5,709.6 | 5,189.1 | 4,563.5 | 2,635.5 | 0.76 | 0.69 | 0.67 | 0.35 | 5.5 | NS | | | | | | | | | |

SD, solid digestate, w/w, weight wise; N, nitrogen; P, phosphorus, K, potassium, 100% synthetic, 180 : 100 : 60 kg N : P₂O₅ : K₂O/ha

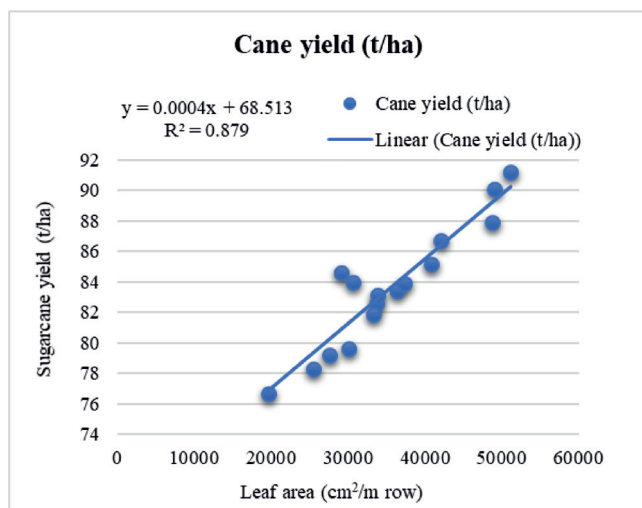


Fig. 1. Correlation between leaf area and cane yield

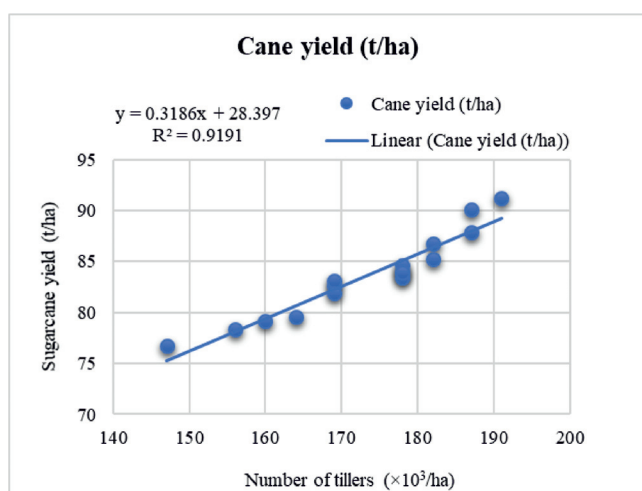


Fig. 2. Correlation between tiller production and cane yield

cane yield and sugarcane tiller count ($r = 0.96^{**}$) (Fig. 1 and Fig. 2), which suggests that higher leaf area enhances photosynthesis, providing more energy for growth, while a higher tiller count increases the number of stalks, directly boosting cane yield.

Hence, from the above study, it can be concluded that the integrated application of synthetic fertilizers along with organic amendments such as solid digest, biochar and liq-

uid slurry was found to be most effective in enhancing growth, cane yield and quality of sugarcane.

REFERENCES

- Anonymous, 2022. Agricultural Statistics at a glance 2022, Ministry of Agriculture and Farmers welfare, Government of India.
- Babu, S., Singh, R., Kumar, S., Rathore, S.S., Yadav, D., Wani, O.A., Raj, R., Yadav, D.K. and Singhl, V.K. 2023. Biochar implications in cleaner agricultural production and environmental sustainability. *Environmental Science: Advances* **2**: 1042.
- Gomez, K.A. and Gomez, A.A. 1984. Statistical procedures for agricultural research. Edn. 2, Jhon Wiley and Sons, New York.
- Gudade, B.A., Malik, G.C., Das, A., Babu, S., Kumar, A., Singh, R. and Bhupenchandra, I. 2023. Effect of biochar levels and integrated nutrient-management practices on agro-physiological performance and productivity of maize (*Zea mays*). *Indian Journal of Agronomy* **67**(4): 380–385.
- Lima, I. and White, P. Jr. 2017. Sugarcane bagasse and leaf residue biochars as soil amendment for increased sugar and cane yields. *International Sugar Journal* **119**(1,421): 382–390.
- Liu, Y., Liao, F., Min, H., Li, Y.R. and Yang, L.T. 2015. Biochar improves sugarcane seedling root and soil properties under a pot experiment. *Sugar Tech* **17**(1): 36–40.
- Mahapatra, B.S., Ramasubramanian, T. and Chowdhury, H. 2001. Organic farming for sustainable agriculture: Global and Indian perspective. *Indian Journal of Agronomy* **54**(2): 178–185.
- Mukhtiar, A., Mahmood, A., Zia, M.A., Ameen, M., Dong, R., Shoujun, Y., Javaid, M.M., Khan, B.A. and Nadeem, M.A. 2024. Role of biogas slurry to reclaim soil properties providing an eco-friendly approach for crop productivity. *Bioresource Technology Reports* **25**: 101716.
- Przygocka-Cyna, K. and Grzebisz, W. 2018. Biogas digestate—benefits and risks for soil fertility and crop quality – an evaluation of grain maize response. *Open Chemistry* **16**: 258–271.
- Rathore, S.S., Mishra, J.S. and Bhatt, B.P. 2021. Recommended best management practices for potential ecosystem services. *Indian Journal of Agronomy* **66**(5th IAC Special issue): 180–190.
- Saurabh, S., Negi, M., Sharma, U., Kumar, P., Chauhan, A., Shavnam and Katoch, V. 2023. A critique of the effectiveness of biochar for managing soil health and soil biota. *Applied Soil Ecology* **191**.
- Verma, S.K., Kumar, S. and Pandey, A.K. 2024. Comparative analysis of the growth, yield attributes and grain yield of *kharif* maize (*Zea mays*) under varying doses of biochar, fertility levels, and biofertilizer treatments. *Indian Journal of Agronomy* **68**(4): 363–367.



Performance of Indian mustard (*Brassica juncea*) under different intercropping systems in Central plain zone of Uttar Pradesh

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ABSTRACT

The field experiment was carried out during winter (*rabi*) season of 2021–22 on Students' Instructional Farm of C.S. Azad University of Agriculture & Technology, Kanpur to assess the performance of Indian mustard under intercropping systems with chickpea, linseed, lentil and pea. The experiment was laid out in Randomized Block Design with 9 treatment combinations replicated thrice. These treatments included Sole Mustard (T₁), Mustard: Chickpea (T₂ 1:1 and T₃ 2:1), Mustard + Lentil (T₄ 1:1 and T₅ 2:1), Mustard + Linseed (T₆ 1:1 and T₇ 2:1), and Mustard + Field Pea (T₈ 1:1 and T₉ 2:1). The results revealed that yield attributes and yield of mustard was significantly higher in sole Mustard and Mustard + Lentil (1:1) intercropping system. The maximum number of branches/plant (37, 38.33 at 30 and 90 DAS, respectively), siliquae/plant (380), seeds/silique (16), test weight (4.89 g), seed yield (2.89 t/ha), stover yield (6.80 t/ha), biological yield (9.68 t/ha), and harvest index (29.80%) were recorded in T₁ (sole Mustard). Among intercropping system T₄ (Mustard + Lentil, 1:1) resulted the maximum number of branches/plant (36.75, 38 at 30 and 90 DAS, respectively), siliquae/plant (375), seeds/silique (16), test weight (4.84 g), seed yield (2.53 t/ha), stover yield (5.90 t/ha), biological yield (8.43 t/ha), harvest index (30.03%) and mustard equivalent yield (2.77 t/ha).

Key words: Chickpea, Intercropping system, Lentil, Linseed, Mustard, Pea, Productivity

Modern agriculture faces challenges such as stagnant production, declining factor productivity, soil degradation, inefficient practices, resource scarcity, high cultivation costs, and low returns to farmers (Kumar *et al.*, 2021). Besides, per capita land availability is decreasing, intensifying the pressure to produce more with limited space, climate change adds new threats like drought, storms, heat waves, rising sea levels, melting glaciers and warming ocean. Horizontal crop production expansion is impractical; the key lies in increasing productivity per unit area through practices like intercropping. To address resource overuse and sustain productivity, incorporating legume crops in rotations and intercropping with cereals offers

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potential benefits over sole cropping systems. Intercropping, the simultaneous cultivation of diverse crops in distinct row combinations on the same land enhances productivity and quality. Widely practiced in India, especially in rainfed regions, it aims to optimize land use and inputs (Ananthi *et al.*, 2017). Successful intercropping depends on selecting compatible crops and proper planting geometry. The practice reduces risks from pests, diseases, and adverse environmental conditions, utilizing resources more efficiently and thereby increasing yields, sustainability, and resource-use efficiency (Kuyah *et al.*, 2021). In India, intercropping, such as combining mustard with lentils, chickpea, pea, and linseed, is crucial for efficient resource utilization in oilseed cultivation, contributing significantly to the country's vegetable oil economy. Mustard (*Brassica juncea* L.), the second-largest oilseed crop in India, is used for edible oil in cooking and frying. It's successfully intercropped with various pulses and oilseeds in diverse agro-ecological zones, thriving in certain tropical and sub-tropical regions as a winter season crop (Sharma and Thakral, 2023). Mustard tolerates moderate salinity, preferring neutral pH soil for optimal growth. The by-products of mustard, such as oil cake, serve as both cattle feed and manure.

The green foliage is used as fodder, and young plants are consumed as a green vegetable, providing essential sulfur in the diet. Linseed (*Linum usitatissimum* L.), also known as flax, is a significant oilseed crop likely first cultivated in southern Asia and the Mediterranean region. With high linolenic-acid content (35–66%), linseed oil is valuable for products like paints, inks, and varnishes (Tripathy *et al.*, 2024).

Pulse crops are vital in agriculture, as they are rich in proteins, carbohydrates, minerals, vitamins, and crude fiber, forming a significant part of the diet for a large population of vegetarian individuals (Kamboj and Nanda, 2018). Additionally, pulses play a unique role in maintaining and restoring soil fertility through biological nitrogen fixation (BNF). Their deep root system and leaf fall contribute to conserving and improving the physical properties of the soil. Chickpea (*Cicer arietinum* L.) is grown both in sole and mixed stands due to its diverse morphology and growth rhythm, suitable for various climates (Das *et al.*, 2017; Meena *et al.*, 2024). As a cool-season legume, it serves as a winter crop in the tropics and a spring or summer crop in temperate regions. India is the leading chickpea producer, contributing to 77% of the world's total production (Raina *et al.*, 2019). Field pea (*Pisum sativum* L.) is a crucial pulse crop cultivated over 6.5 million ha globally, producing approximately 10.2 million tonnes. Mature peas are highly nutritious, containing digestible protein (18–35%), starch (20–50%), sugars (4–10%), fat (0.6–1.5%), cellulose (2–10%), and essential minerals and vitamins (Prajapati *et al.*, 2024). Field pea serves multiple purposes, acting as forage for animals in hay, pasture, and silage, while in semi-arid areas; it is used for seed and green manure. Lentil (*Lens culinaris* Medik.), a major pulse crop, is prominently grown in India, Canada, Turkey, USA, Syria, and Australia (Laskar *et al.*, 2019). Lentil thrives in sub-marginal lands with low inputs, particularly under water-limited conditions, earning its nickname as the “poor man's meat. Nutritionally, lentil seeds are valued for their high protein content (up to 30%), vitamins, and essential minerals, being low in fat and cholesterol-free. To maximize returns per unit land area, intercropping of suitable crop with optimum row ratio is crucial. Hence, the experiment was undertaken with an objective to identify most compatible intercrops and row ratios for mustard.

The field experiment was conducted at Chandra Shekhar Azad University of Agriculture and Technology in Kanpur, Uttar Pradesh, India during *rabi* season of 2021–22 on Student's Instructional Farm (SIF), situated in the central region of North India's sub-tropical semi-arid tract (26° 29' 35" N latitude, 80° 18' 25" E longitude). The location is Gangetic plain at an elevation of approximately

125.9m above MSL. Kanpur experiences a semi-arid climate with fertile alluvial soil, receiving around 937mm of annual rainfall, mainly from mid-June to September. Minimum temperature winters range from 2°C to 3°C, with occasional rain and frost from late Dec. to mid-January and May and June are the hottest months reaching 44°C to 47°C or higher. Relative humidity ranges from 80–90% from July to March, decreasing to 40–50% by April end and staying at 60% up to June. The experimental field soil is sandy clay loam with specific measurements: pH (7.30), EC (0.33 ds/m), Organic Carbon (0.43%), available N (215 kg/ha), available P (16.5 kg/ha), available K (147. Kg/ha), and S (10 ppm). The experiment were laid out in Randomized Block Design with three replications, having nine treatment combinations viz., T₁ Sole Mustard, T₂ Mustard + Chickpea (1:1), T₃ Mustard + Chickpea (2:1), T₄ Mustard: Lentil (1:1), T₅ Mustard + Lentil (2:1), T₆ Mustard + Linseed (1:1), T₇ Mustard + Linseed (2:1), T₈ Mustard + Field Pea (1:1), T₉ Mustard + Field Pea (2:1). Crop varieties included ‘Azad Mahak’ (Mustard), ‘Uma’ (Linseed), ‘Avrodhi’ (Chickpea), ‘KL-320’ (Lentil), and ‘Sapna’ (Field Pea). Field preparation began post-kharif crop harvest, involving pre-sowing irrigation for seed germination. Fertilizers were applied as recommended for each crop and sowing was done on October 28, 2021, with specified row ratios and plant spacing in a replacement series for intercropping. Irrigation was provided at branching and pod-filling stages, with manual weeding and disease control using Matco (metalaxyl 8% + mancozeb 64%) @ 1.5 kg/ha. Harvesting was done manually when pods/silique turned yellowish brown having around 38% moisture content. Harvested plants were sun-dried and brought to the threshing floor. Threshing was, done by using wooden sticks, and seed weight was recorded. Stover yield was calculated by subtracting seed weight from the total biological yield. Specifically, data were gathered from five identified plants within each plot. Various mustard-related parameters, viz., growth and yield were recorded on per-plot basis. Subsequently, the collected data underwent appropriate statistical analysis following the method detailed by to evaluate potential significant differences among treatment means. The Least Significant Difference (LSD) test was employed to compare the treatment means at 5% significance level.

The number of branches per plant of mustard recorded significant differences at 60 and 90 DAS (Table 1). The maximum number of primary branches per plant of mustard was found in T₁ (sole mustard). In intercrops the maximum number of branches/plant was observed in T₄ (Mustard + Lentil; 1:1), which was significantly higher among all intercropping treatments. Number of siliquae/plant and seeds/silique exhibited a significant difference among

Table 1. Effect of intercropping systems on yield attributes of mustard

| Treatment | Branches/plant | | Siliquae/plant | Seeds/siliquae | Test weight (g) |
|---|----------------|--------|----------------|----------------|-----------------|
| | 60 DAS | 90 DAS | | | |
| T ₁ Sole mustard | 37.00 | 38.33 | 380.00 | 16.00 | 4.89 |
| T ₂ Mustard + Chickpea (1:1) | 35.84 | 37.33 | 360.50 | 15.66 | 4.81 |
| T ₃ Mustard + Chickpea (2:1) | 35.41 | 37.08 | 355.33 | 16.00 | 4.75 |
| T ₄ Mustard + Lentil (1:1) | 36.75 | 38.00 | 375.00 | 16.00 | 4.84 |
| T ₅ Mustard + Lentil (2:1) | 36.42 | 37.59 | 365.66 | 16.00 | 4.81 |
| T ₆ Mustard + Linseed (1:1) | 35.00 | 36.34 | 350.00 | 16.00 | 4.36 |
| T ₇ Mustard + Linseed (2:1) | 34.33 | 35.58 | 344.33 | 15.66 | 4.32 |
| T ₈ Mustard + Pea (1:1) | 34.00 | 34.83 | 339.66 | 15.66 | 4.20 |
| T ₉ Mustard + Pea (2:1) | 33.00 | 34.33 | 335.33 | 15.33 | 4.15 |
| SEm± | 0.56 | 0.33 | 3.380 | 0.263 | 0.067 |
| CD (P=0.05) | 1.692 | 1.00 | 10.221 | NS | 0.202 |

various intercrops. In mustard, the siliqua/plant and seeds/siliqua was significantly higher in T₁, followed closely by T₄. Both T₁ and T₄ were statistically at par but significantly superior over other combinations of mustard intercrops. However, the lowest results were recorded when mustard was intercropped with pea (T₉). Test weight (4.88) was the maximum in sole mustard crop, followed by T₄, T₅, T₂ and T₃ which were statistically at par but significantly superior over rest of the intercrop combinations. However, the minimum test weight in mustard crop recorded where mustard was grown with pea (4.20 and 4.15 g). The intercropping system's effect on yield attributes by optimizing resource use, managing pests and diseases were more effective due to modifying the microclimate, enhancing biodiversity, providing yield stability, influencing competition and facilitation among crops, incorporating beneficial crop rotation effects, and improving overall soil structure. Similar findings were reported by Devi *et al.* (2014), Patel *et al.* (2022) and Singh *et al.* (2016).

The seed, stover, biological yield and harvest index (Table 2) of mustard showed significant variations among

the different intercrop combinations. The significantly maximum yield was produced by sole mustard T₁ followed by T₄, T₂, T₅ and T₃ whereas T₉ recorded the minimum yield where mustard was intercropped with pea. The intercropping system influence yield by optimizing resource allocation and interactions among different crops contribute to a more balanced and resilient agricultural system, affecting the distribution of yields and overall crop performance. The intercrop combinations exhibited notable variations, with the mustard equivalent yield showing statistical significance. The highest mustard equivalent yield (MEY) was recorded in T₁ (sole mustard) crop, possibly attributed to its higher yield levels compared to other intercrops. Among the various intercropping system, significantly higher mustard equivalent yields were observed in T₄ and T₆ attributed to the combination of high market prices and the superior yields of lentil and linseed compared to other intercrops. These findings align with the results reported by Devi *et al.*, 2014; Kour *et al.*, 2015 and Tripathi *et al.*, 2005.

Intercropping significantly influences crop productivity.

Table 2. Effect of intercropping systems on productivity of mustard

| Treatment | Seed yield (t/ha) | Stover yield (t/ha) | Biological yield (t/ha) | Harvest index (%) | MEY (t/ha) |
|---|-------------------|---------------------|-------------------------|-------------------|------------|
| T ₁ Sole mustard | 2.885 | 6.795 | 9.680 | 29.80 | 2.885 |
| T ₂ Mustard + Chickpea (1:1) | 2.499 | 5.822 | 8.321 | 30.03 | 2.715 |
| T ₃ Mustard + Chickpea (2:1) | 2.460 | 5.731 | 8.191 | 30.03 | 2.567 |
| T ₄ Mustard + Lentil (1:1) | 2.532 | 5.899 | 8.431 | 30.03 | 2.774 |
| T ₅ Mustard + Lentil (2:1) | 2.472 | 5.759 | 8.231 | 30.03 | 2.613 |
| T ₆ Mustard + Linseed (1:1) | 2.410 | 5.615 | 8.025 | 30.03 | 2.755 |
| T ₇ Mustard + Linseed (2:1) | 2.390 | 5.568 | 7.958 | 30.03 | 2.528 |
| T ₈ Mustard + Pea (1:1) | 2.400 | 5.592 | 7.992 | 30.03 | 2.693 |
| T ₉ Mustard + Pea (2:1) | 2.370 | 5.522 | 7.892 | 30.03 | 2.497 |
| SEm± | 0.039 | 0.105 | 0.076 | 0.230 | 0.043 |
| CD (P=0.05) | 0.120 | 0.318 | 0.229 | NS | 0.132 |

The study focused on the performance of Indian mustard within an intercropping system with chickpea, linseed, lentil, and field pea. The higher yield attributes and yield of mustard were observed with the sole mustard (T₁). However, in the intercropping system Mustard + Lentil; 1:1 (T₄) showed close noteworthy results. These results underscore the potential of intercropping, specifically the Mustard + Lentil (1:1) system, as an effective strategy to enhance crop productivity and economic viability in the cultivation of Indian mustard during winter season.

REFERENCES

- Ananthi, T., Amanullah, M.M. and Al-Tawaha, A.R.M.S. 2017. A review on maize-legume intercropping for enhancing the productivity and soil fertility for sustainable agriculture in India. *Advances in Environmental Biology* **11**(5): 49–64.
- Das, S., Devi, K.N., Athokpam, H.S., Lungdim, J. and Longjam M. 2017. Chickpea (*Cicer arietinum* L.) based intercropping system with rapeseed (*Brassica napus* L.) on growth, yield and competition indices. *Environment and Ecology* **35**(1B): 427–430.
- Devi, K.N., Shamurailatpam, D., Singh, T.B., Athokpam, H.S., Singh, N.B., Singh, N.G. and Devi, L.S. 2014. Performance of lentil (*Lens culinaris* M.) and mustard (*Brassica juncea* L.) intercropping under rainfed conditions. *Australian Journal of Crop Science* **8**(2): 284–289.
- Kamboj, R. and Nanda, V. 2018. Proximate composition, nutritional profile and health benefits of legumes—a review. *Legume Research-An International Journal* **41**(3): 325–332.
- Kour, R., Sharma, B.C., Kumar, A., and Sharma, N. 2015. Yield analysis of chickpea (*Cicer arietinum*) + Indian mustard (*Brassica juncea*) intercropping system through computation of intercropping indices. *Indian journal of Agronomy* **60**(3): 381–385.
- Kumar, N., Chhokar, R.S., Meena, R.P., Kharub, A.S., Gill, S.C., Tripathi, S.C. and Singh, G.P. 2021. Challenges and opportunities in productivity and sustainability of rice cultivation system: a critical review in Indian perspective. *Cereal Research Communications* 1–29.
- Kuyah, S., Sileshi, G.W., Nkurunziza, L., Chirinda, N., Ndayisaba, P.C., Dimobe, K. and Öborn I. 2021. Innovative agronomic practices for sustainable intensification in sub-Saharan Africa. A review. *Agronomy for Sustainable Development* **41**: 1–21.
- Laskar, R.A., Khan, S., Deb, C.R., Tomlekova, N., Wani, M.R., Raina, A. and Amin, R. 2019. Lentil (*Lens culinaris* Medik.) diversity, cytogenetics and breeding. *Advances in Plant Breeding Strategies: Legumes* **7**: 319–369.
- Meena, S., Meena, L., Yadav, S., Jadon, C., Dhakad, U., Lal, M. and Singh, P. 2024. Chickpea (*Cicer arietinum*)-based intercropping systems in Rajasthan's Hadoti region: Productivity and economic viability. *Indian Journal of Agronomy* **69**(1): 54–60.
- Prajapati, R., Meena, S.L., Kumar, D., Rathore, S.S., Varghese, C., Tripathy, S., Meena, D.K., Meena, P. 2024. Yield, nutrient uptake and economics of Indian mustard (*Brassica juncea*) as affected by split and foliar application of potassium. *Indian Journal of Agronomy* **69**(2): 220–222. <https://doi.org/10.59797/ija.v69i2.5512>
- Raina, A., Khan, S., Wani M.R., Laskar, R.A. and Mushtaq, W. 2019. Chickpea (*Cicer arietinum* L.) cytogenetics, genetic diversity and breeding. *Advances in Plant Breeding Strategies: Legumes* **7**: 53–112.
- Sharma, S.K., Thakral, S.K., 2023. Assessment of yield and profitability of Indian mustard (*Brassica juncea*) with foliar fertilization under rainfed condition. *Indian Journal of Agronomy* **68**(3): 300–304. <https://doi.org/10.59797/ija.v68i3.2811>
- Singh, R.K., Singh, U. and Upadhyay, P.K. 2016. Production potential and competitive ability of wheat (*Triticum aestivum*) + Indian mustard (*Brassica juncea*) intercropping under varying row ratio, farmyard manure and fertilizer level of middle Gangetic Plain of India. *Indian journal of Agronomy* **61**(4): 460–466.
- Tripathi, H.N., Chand, S. and Tripathi, A.K. 2005. Biological and economic feasibility of chickpea (*Cicer arietinum*) + Indian mustard (*Brassica juncea*) cropping systems under varying levels of phosphorus. *Indian Journal of Agronomy* **50**(1): 31–34.
- Tripathy, S., Meena, S.L., Dhar, S., Singh, S., Meena, P., 2024. Impact of row ratios and nutrient management practices on yield, economics and nutrient uptake of mustard + chickpea intercropping system. *Indian Journal of Agronomy* **69**(2): 172–176. <https://doi.org/10.59797/ija.v69i2.5503>
- Patel, S., Rathore, S.S., Shekhawat, Kapila., Rameti, Singh, V.K., Singh, R.K., Babu, Subhash., Iquebal, Mir Asif. 2022. Sustaining Indian mustard (*Brassica juncea*) productivity and soil health through varietal diversification under diverse production systems. *Indian Journal of Agronomy* **67**(1): 105–107. <https://doi.org/10.59797/ija.v67i1.98>

Effect of integrated nutrient management on the growth and yield of Yellow Sarson (*Brassica rapa* var. *yellow sarson*) under guava (*Psidium guajava*) based agri-horti system

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ABSTRACT

An experiment was conducted during the winter (*rabi*) season of 2021–22 to evaluate the effect of integrated nutrient management on the growth and yield of yellow sarson under guava based agri-horti system. The field experiment comprised 8 treatment, viz., T₁, Control; T₂, 100% RDF + 30 kg S + 5 kg Zn; T₃, 50% RDF + 15 kg S + 2.5 kg Zn + 2.5 t/ha FYM+ 2 spray of nano urea; T₄, 50% RDF + 15 kg S + 2.5 kg Zn + 5 t/ha FYM+ one spray of nano urea; T₅, 75% RDF + 22.5 kg S + 3.7 kg Zn + 2.5 t/ha FYM + 2 spray of nano urea; T₆, 75% RDF + 22.5 kg S + 3.7 kg Zn + 5 t/ha FYM + 1 spray of nano urea; T₇, 100 % RDF + 30 kg S + 5 kg Zn + 2.5 t/ha FYM; T₈, 100% RDF + 30 kg S + 5 kg Zn + 5 t/ha FYM, was laid out in randomized block design, with 3 replications. The results revealed that application of 75% RDF + 22.5 kg S + 3.7 kg Zn + 2.5 t/ha FYM + 2 spray of nano urea at 30-35 DAS and pre-flowering stage (T₅) gave significantly higher growth and yield attributes such as plant height (141.03 cm), dry matter accumulation (37.76 g/plant), no. of siliqua (142/plant), siliqua length (6.67 cm), test weight (3.43 g) as well as seed yield (1.49 t/ha) and stover yield (3.54 t/ha) as compared to control. The highest amount of nitrogen, phosphorus, potassium and sulphur uptake by plant was also observed in the treatment T₅. These findings provide valuable insights for farmers and researchers aiming to optimize nutrient management strategies and improve crop productivity in similar agri-horti systems.

Key words: Agri-horticulture, Guava, Integrated nutrient management, Yellow sarson, Yield

The combination of agricultural crops, mostly legume crops, and perennial fruit crops will give a very good source of revenue for farmers livelihood as well as promoting its products, making the agri-horti system the most desired system as opposed to other systems that exaggerate output (Lal *et al.*, 2014). The guava-rapeseed & mustard based agroforestry approach is considered to be the finest choice for intercropping. Guava (*Psidium guajava* L.) is a fast-growing fruit crop that can be planted throughout the country, with the exception of higher hills. Whereas, Rapeseed & Mustard is one of the most important oilseed crops (Raj *et al.*, 2019). It is currently the world's third most

important oilseed crop in terms of production and area. It occupied 8.8 million hectares, with a production of 12.4 million tonnes and a productivity of 1419 kg/ha for 2021-22 (Anonymous, 2022).

Now a days, use of inorganic fertilizers and pesticides has become an important tool to increase crop production. However, a major portion of the applied chemical fertilizer is lost through the leaching, runoff, emission and volatilization which resulted in economic losses and environmental problems. Integrated nutrient management (INM) plays a crucial role in enhancing soil fertility and plant nutrient availability, achieved through the synergistic combination of inorganic and organic fertilizers along with biofertilizers (Mohanty *et al.*, 2019). Farmyard manure (FYM) is one of the important squares of nutrient management because it is cheap and easy to get which improves the soil physical, chemical and biological properties (Meena *et al.*, 2021). However, a substantial amount of manure is normally recommended for a long-term and greater soil productivity (Cai *et al.*, 2020). Inadequate use of organic manures and fertilizers as well as total reliance on chemical fertilizers

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has been recognized as major barriers to rapeseed & mustard production. The appropriate application of fertilizers helps to supply all the essential nutrients to plants which play a critical role in maximizing the yield potential of rapeseed & mustard. Additionally, crop nutritional deficiencies may be resolved with the use of nanotechnology. Nano fertilizers, with their unique properties, enhance plant performance by significantly boosting production through ultra-efficient absorption (Navya *et al.*, 2022).

With the importance of the combined effect of organic and inorganic nutrients, present investigation was conducted to study the effect of integrated nutrient management on the growth and yield of yellow sarson under guava based agri-horti system.

The experiment was conducted during the winter (*rabi*) season of 2021-22 at the Agricultural Research Farm, Rajiv Gandhi South Campus, Banaras Hindu University, Barkachha, Mirzapur, Uttar Pradesh. This place typically experiences semi-arid to sub-humid climates, with high and low precipitation, moderate humidity, and seasonal temperature fluctuations. The seed loam sandy loam soil in the experimental field exhibited low levels of soil organic carbon (0.36%) and nitrogen (175.2 kg/ha), but high levels of potassium (157.68 kg/ha) and phosphorus (18.5 kg/ha). Both pH (6.5) and electrical conductivity (0.23 dS/m) of the soil were within the typical range. The experiment followed a randomized block design (RBD) with three replications. The study included eight treatments, namely Control (T_1), 100% RDF(80-40-40) kg/ha +30 kg S+5kg Zn (T_2), 50% RDF+15 kg S+2.5 kg Zn+2.5 t/ha FYM+two sprays of nano urea (T_3), 50% RDF+15 kg S+2.5 kg Zn+5 t/ha FYM+one spray of nano urea (T_4), 75% RDF+22.5kg S+3.7kg Zn+2.5 t/ha FYM+two sprays of nano urea (T_5), 75% RDF+22.5 kg S+3.7 kg Zn+5 t/ha FYM+one spray of nano urea (T_6), 100% RDF(80-40-40 kg/ha) +30kg S+5kg Zn+2.5 t/ha FYM (T_7), and 100% RDF(80-40-40) kg/ha +30 kg S+5 kg Zn+5 t/ha FYM (T_8). The gross and net plot sizes were: 5 m × 3 m and 4 m × 2.1 m, respectively.

After the final field preparation, the seeds of yellow sarson variety “Pitambari” was sown in furrows at the rate of 5 kg/ha at a uniform distance of 45 cm between rows and 15 cm distance between plant to plant, thinning is done after full emergence to maintain optimum plant population. The sowing was done in second fortnight of October between the alleys of eighteen years old guava plantation (Lucknow-49) which was planted in August 2006–2007 at spacing 7m×7m. Well-decomposed FYM was applied to all the experimental units as per different treatment combinations. The field was fertilized with recommended doses of N: P: K (80: 40: 40 kg/ha) for the rapeseed crop as per the treatment. The study employed urea, di-ammonia phosphate (DAP), muriate of potash (MOP), elemental sulphur

and monozinc sulphate (MZS), respectively as sources of nutrients. Half dose of nitrogen and full dose of phosphorus, potassium, sulphur and zinc as per treatment were applied in furrows after mixing with moist soil. The rest half nitrogen was top dressed through urea after first irrigation. Nano urea is applied @ 500 ml/acre at initial growth stage 30–35 days after sowing and before flowering.

In each plot, 5 plants were tagged for taking all observations. Siliquae were picked at nearly 90% of the crop maturity stage. Seed yield was estimated on a per plot basis and converted to seed yield per hectare in tonnes. Statistical analysis was made to determine the significance between the means of treatment and to draw a valid conclusion. Data obtained from various parameters observations were analyzed statistically by adopting the appropriate “Analysis of Variance method”. The significance of the treatment effect was evaluated with the help of the ‘F’ test (Variance ratio).

The data revealed that application of 75% RDF + 22.5 kg S + 3.7 kg Zn + 2.5 t/ha FYM + 2 spray of nano urea (T_5) gave significantly higher plant height (141 cm) at harvest (Table 1). Increased plant height due to integration of organic and inorganic nutrients application are in accordance with that reported by Bhari *et al.* (2000). Significantly highest dry matter accumulation/plant (37.76 g) were observed with application of 75% RDF and 22.5 kg S + 3.7 kg Zn + 2.5 t/ha FYM + 2 spray of nano urea (T_5) over other nutrient management practices. The application of nitrogen and nano urea increases cell size, resulting in morphologically increased plant height also found that improved nutrition taller plants produced better chlorophyll synthesis, which increased photosynthesis and dry matter accumulation as a result of more chances for photosynthate generation (Sharma and Thkaral, 2023). In contrast, the control treatment, which received no fertilizer application, recorded the minimum dry matter accumulation due to the absence of any nutrient supplementation.

Significantly maximum numbers of siliqua/plant (142), siliqua length (6.67cm) and test weight (3.43 g) were recorded in treatment T_5 , which was at par with T_6 and T_8 . Significantly highest seed (1.4 t/ha) and stover (3.5 t/ha) yield were observed in the treatment T_5 as compared to all the treatments. Also, treatment T_5 recorded significantly higher biological yield (4.6 t/ha) and harvest index (29.61%) which were found at par with T_6 and T_8 . (Table 1). The increase in seed, stover and biomass production might be attributed to improvements in growth and yield-attributing characteristics, as well as enhanced photosynthetic activity. A considerable increase in stover production might be attributed to enhanced dry matter accumulation beginning with the early stages of crop growth and lasting for 130 days under conditions of improved photosynthetic

Table 1. Effect of INM on various growth, yield attributes, yield and harvest index

| Treatments* | Plant height (cm) at harvest | Dry matter accumulation (g/plant) at harvest | Number of siliqua/plant | Length of siliqua (cm) | Test weight (g) | Seed yield (t/ha) | Stover yield (t/ha) | Biological yield (t/ha) | Harvest index (%) |
|----------------|------------------------------|--|-------------------------|------------------------|-----------------|-------------------|---------------------|-------------------------|-------------------|
| T ₁ | 123.20 | 28.27 | 116 | 3.40 | 2.57 | 0.71 | 1.87 | 2.71 | 26.06 |
| T ₂ | 129.40 | 32.22 | 129 | 5.00 | 3.23 | 1.08 | 2.74 | 3.82 | 28.18 |
| T ₃ | 125.73 | 29.89 | 121 | 3.60 | 3.00 | 0.87 | 2.27 | 3.13 | 27.65 |
| T ₄ | 127.43 | 31.38 | 125 | 3.77 | 3.11 | 0.97 | 2.46 | 3.43 | 28.30 |
| T ₅ | 141.03 | 37.76 | 142 | 6.67 | 3.43 | 1.49 | 3.55 | 4.69 | 29.61 |
| T ₆ | 138.22 | 35.17 | 138 | 6.40 | 3.37 | 1.29 | 3.20 | 4.45 | 28.70 |
| T ₇ | 133.41 | 33.95 | 129 | 5.77 | 3.26 | 1.17 | 2.98 | 4.15 | 27.81 |
| T ₈ | 135.56 | 34.66 | 34 | 6.10 | 3.37 | 1.24 | 3.10 | 4.33 | 28.53 |
| SEm± | 2.00 | 0.41 | 3.83 | 0.36 | 0.06 | 0.05 | 0.10 | 0.17 | 0.47 |
| CD (P=0.05) | 6.14 | 1.26 | 11.74 | 1.11 | 0.10 | 0.14 | 0.32 | 0.51 | 1.45 |

*Treatment details are given under materials and methods section.

efficiency and nutrient accumulation. Singh *et al.* (2014) and Meena *et al.* (2021) also reported the same observation.

These results highlight the importance of INM and the use of nano urea in enhancing yield attributes and overall crop productivity in yellow sarson cultivation.

The INM treatment consisting of 75% RDF, 22.5 kg of S, 3.7 kg of Zn, 2.5 t/ha of FYM, and two sprays of nano urea (T₂) exhibited maximum harvest index (29.61%) and biological yield (4.6 t/ha). This treatment was statistically at par with the treatment involving 75% RDF, 22.5 kg S, 3.7 kg Zn, 5 t/ha FYM, and one spray of nano urea (T₆), followed by the T₈ treatment of 100% RDF, 30 kg S, 5 kg Zn, and 5 t/ha FYM, which also recorded significantly higher harvest index compared to the other treatments. The control treatment exhibited the minimum harvest index (26.06%). The higher harvest index in T₅, T₆, and T₇ could be attributed to the increased seed and stover yield achieved through INM.

The maximum nitrogen (56.57 kg/ha), phosphorus (6.85 kg/ha), potassium (42.82 kg/ha) and sulphur (11.59 kg/ha) uptake in plant (seed + stover) recorded in the treatment T₅ as compared to rest of all the treatments. Whereas, minimum nitrogen, phosphorus and potassium uptake in rape-seed plant (seed + stover) was recorded in the treatment control. This may be attributed to higher amount of NPK application, which increase the nitrogen content and uptake and also have positive effect on the phosphorus and potassium content in seed and stover. The increased nutrient uptake in the organic manure treated plots could be attributed to the additional nutrients provided by these organics, as well as the organics providing a conducive physical environment that facilitated better root growth and absorption of nutrients from both native and applied sources, which ultimately favoured the highest nutrient uptake. Plant nutrients, particularly nitrogen, phosphorus, potassium and sulphur must be given in a balanced manner. It could be linked to a healthy root system that efficiently aids

Table 2. Effect of INM on total nitrogen, phosphorus, potassium and sulphur uptake

| Treatments* | Total nitrogen uptake (kg/ha) | Total phosphorus uptake (kg/ha) | Total potassium uptake (kg/ha) | Total sulphur uptake (kg/ha) |
|----------------|-------------------------------|---------------------------------|--------------------------------|------------------------------|
| T ₁ | 23.55 | 2.71 | 17.66 | 3.41 |
| T ₂ | 37.56 | 4.30 | 30.22 | 5.97 |
| T ₃ | 29.56 | 3.37 | 22.83 | 4.43 |
| T ₄ | 33.44 | 3.87 | 25.55 | 5.02 |
| T ₅ | 56.57 | 6.85 | 42.82 | 11.59 |
| T ₆ | 47.86 | 5.67 | 37.48 | 9.33 |
| T ₇ | 41.32 | 4.82 | 33.34 | 7.43 |
| T ₈ | 44.06 | 5.20 | 35.46 | 8.54 |
| SEm± | 1.41 | 0.17 | 1.51 | 0.34 |
| CD (P=0.05) | 4.34 | 0.54 | 4.63 | 1.08 |

*Treatment details are given under materials and methods section

in greater nutrient absorption from the soil, resulting in increased biomass and nutrient concentration, and therefore higher nutrient uptake. This finding is consistent with the studies conducted by Meena *et al.* (2022).

Thus, it can be concluded that application of 75% RDF + 22.5 kg S + 3.7 kg Zn + 2.5 t/ha FYM+ two spray of nano urea enhance the growth, yield and nutrient uptake of rapeseed under guava based agri- horti system.

REFERENCES

- Anonymous. 2022. Directorate of Economics and Statistics, Department of Agriculture, Cooperation & Farmers Welfare, Ministry of Agriculture & Farmers Welfare, Government of India. Agricultural Statistics at a Glance.
- Lal, G. and Dayal, H. 2014. Effect of integrated nutrient management on yield and quality of acid lime (*Citrus aurantifolia Swingle*). *African Journal of Agricultural Research* **9**(40): 2,985–2,991.
- Sharma, S.K. and Thakral, S.K. 2023. Assessment of yield and profitability of Indian mustard (*Brassica juncea*) with foliar fertilization under rainfed condition. *Indian Journal of Agronomy* **68**(3): 300–304 <https://doi.org/10.59797/ija.v68i3.2811>.
- Bhari, N.R., Siag, R.K. and Mann, P.S. 2000. Response of Indian mustard (*Brassica juncea* L.) to nitrogen and phosphorus on Tropopsamments of north-western Rajasthan, *Indian Journal of Agronomy* **45**(4): 746–751.
- Cai, Z., Wang, B., Zhang, L., Wen, S., Xu, M., Misselbrook, T.H. and Gao, S. 2021. Striking a balance between N sources: Mitigating soil acidification and accumulation of phosphorous and heavy metals from manure. *Science of the Total Environment* **754**, 142189.
- Meena, V.S., Meena, M.K., Meena, M.D.M., Jat, R.S., Choudhary, R.L., Singh, H. and Rai, P. K. 2021. Improvement in growth and yield of Indian mustard by using micro and secondary nutrients fortified FYM in calcareous soil. *Journal of Oilseed Brassica* **12**(1): 38–43.
- Raj, A., Jhariya, M.K., Yadav, D.K. and Banerjee, A. 2019. Agroforestry with horticulture: A new strategy toward a climate-resilient forestry approach. In *Agroforestry and Climate Change*. Apple Academic Press, First Edition, Florida, USA, pp. 67–96.
- Singh, R., Singh, A.K. and Kumar, P. 2014. Performance of Indian Mustard (*Brassica juncea* L.) in Response to Integrated Nutrient Management. *Journal of AgriSearch* **1**(1): 9–12.
- Mohanty S, Nayak A.K., Tripathi R, Shahid M, Panda B.B., Vijayakumar S, Mohapatra S.D., Priyadarsini S., Saha S., Sarangi D.R., Swain C.K., Besra B., Nagothu. U.S. and Pathak H. Integrated Nutrient Management for Sustainable Rice Production. September 2019. Technology Brief No. 2.
- Meena, B.S., Narolia, R.S., Nagar, G., Meena, S.N. and Meena, D.S. 2022. Effect of sowing window, planting geometry and nutrient-management on yield, nutrient uptake and economics of Indian mustard in Vertisols of south-eastern Rajasthan. *Indian Journal of Agronomy* **67**(1): 50–57.
- Navya, K., Sai Kumar, R., Krishna Chaitanya, A. and Sampath, O. 2021. Effect of nano nitrogen in conjunction with urea on growth and yield of mustard (*Brassica juncea* L.) in Northern Telangana Zone. *Biological Forum – An International Journal* **14**(3): 95–99.

