

## Conservation-agriculture practices and weed-management effects on productivity, water and energy-use efficiency of rainfed pearl millet *(Pennisetum glaucum)*

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## ABSTRACT

A field experiment was conducted during the rainy (kharif) season of 2019 at the ICAR-Indian Agricultural Research Institute, New Delhi, to study the effect of different tillage and weed-management practices on productivity, water and energy-use efficiency of pearl millet [Pennisetum glaucum (L.). R. Br.]. The experiment was laid out in a split-plot design, with tillage in main plot, viz. conventional tillage (CT), zero tillage (ZT), zero tillage + residue (ZT + R) 3 t/ha, and weed management in subplot, viz. weedy check, hand-weeding (HW) at 30 and 50 days after sowing (DAS), pre-emergence (PE) atrazine @ 0.75 kg/ha followed by (fb) post-emergence (PoE) 2,4-D @ 0.75 kg/ha, atrazine @ 0.75 kg/ha PE, atrazine @ 0.75 kg/ha PE fb tembotrione @ 0.05 kg/ha PoE, atrazine @ 0.75 kg/ha PE fb tembotrione @ 0.075 kg/ha PoE, atrazine @ 0.75 kg/ha PE fb tembotrione @ 0.10 kg/ha PoE in 3 replications. The performance of ZT + R was significantly better in terms of grain (2.40 t/ha) and stover yields (7.90 t/ha) compared to CT, but was at par with ZT. Similarly, HW at 30 and 50 DAS resulted in significantly higher grain (2.53 t/ ha) and stover yields (8.13 t/ha) than the other weed-management practices, but was at par with atrazine 0.75 kg/ ha PE fb 2,4-D 0.75 kg/ha PoE. Higher water-use efficiency (6.45 kg/ha-mm) was recorded under HW at 30 and 50 DAS among the weed-management practices. Net energy output (111,046 MJ/ha) and energy-use efficiency (11.9) were also significantly higher in atrazine 0.75 kg/ha PE fb tembotrione 0.05 kg/ha PoE than the control. Cultivating pearl millet under ZT + R with either 2 HW at 30 and 50 DAS or atrazine 0.75 kg/ha PE fb 2,4-D 0.75 kg/ha PoE was found-energy efficient and eco-friendly under rainfed conditions for higher productivity.

Key words: Conservation agriculture, Energetics, Pearl millet, Weed-management, Yield attributes

Pearl millet [*Pennisetum glaucum* (L.) R. Br.] is the sixth important cereal staple food crop grown in the world's arid and semi-arid tropical environments. It is largely grown in rainy conditions in arid and semi-arid regions, dominated by coarse-textured soils with low water-holding capacity, high infiltration rates, and low soil fertility. The productivity of pearl millet is low because of several constraints such as its cultivation in rainfed conditions coupled with fertility-deficient soils, the heavy incidence of ergot disease, use of non-descript strains, severe weed infestation, and poor water-management practices (Jain, 2017). Rainfed agriculture is practiced in about 52% of the

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<sup>1</sup>**Corresponding author's Email:** munnychinyo57@gmail.com <sup>1</sup>Ph.D. Scholar, Division of Agronomy, Gobind Ballabh Pant University of Agriculture and Technology, Pantnagar, Uttarakhand 263 145; <sup>2</sup>Principal Scientist, Division of Agronomy, <sup>3</sup>Research Associate, Division of Agricultural Physics, ICAR-Indian Agricultural Research Institute, New Delhi 110 012 total net cultivated area (140 Mha), which is widely distributed in different agro-ecologies of the country and contributes nearly 44% to the total food grain production. Tillage is the most important component of crop-production practices as it helps in providing a favourable environment for seed-germination and improves the efficiency of inputs.

Conservation agriculture (CA) is an effective soil-management practice that minimizes the effects on composition, structure, and natural biodiversity and reduces erosion and degradation. Intensification of CA-based system in the vulnerable semi-arid tropics provides opportunities to conserve and utilize the fatiguing natural resources more efficiently, increase resilience to anomalous climatic events, and increase productivity and farmers' profitability while minimizing production cost and energy use. The benefits of CA are more apparent under rainfed conditions where it helps in capturing and retaining moisture, thereby increasing yield (Pittelkow *et al.*, 2014). Weed infestation particularly in the initial years, is one of the major challenges in CA, as weeds severely affect crop growth, yield, and farm March 2023]

profitability. Under such circumstances, effective and economic weed-management practices are of utmost importance to realize effective control of weeds in the pearl millet crop. Optimization of pearl millet yield under CA system, requires early and frequent hand-hoeing or use of herbicides to manage weed populations as this system increases early, mid and late-season weed growth (Farooq *et al.*, 2011; Mashingaidze *et al.*, 2012). Keeping the above facts in view, an experiment was conducted to study the productivity, water, and energy-use efficiency of rainfed pearl millet as influenced by different tillage and weed management practice in the semi-arid tropics.

The field experiment was conducted during the rainy (kharif) season of 2019 at the research farm of the Division of Agronomy, ICAR-Indian Agricultural Research Institute, New Delhi (28°38'N, 77°11'E, and 228.6 m above mean sea-level). During the crop duration (July-October), the mean minimum, maximum temperature, relative humidity, and total rainfall were 31 to 6.5°C, 21.8 to 28°C, 33 to 98%, 780 mm respectively. The soil belongs to Inceptisols, having a sandy-loam texture with 7.5 pH. The experiment was laid out in a split-plot design with 3 replications. Main plot treatments consisted of 3-tillage practice i.e. conventional tillage, zero tillage without residue, zero tillage with residue 3 t/ha; and sub-plots received 7 weed-management practices i.e. weedy check, hand-weeding (HW) at 30 and 50 days after sowing (DAS), pre-emergence (PE) application of atrazine @ 0.75 kg/ha *fb* post-emergence (PoE) application of 2, 4-D @ 0.75 kg/ha at 30 DAS, atrazine @ 0.75 kg/ha (PE), atrazine @ 0.75 kg/ha (PE) fb tembotrione @ 0.05 kg/ha (PoE) at 30 DAS, atrazine @ 0.75 kg/ha (PE) fb tembotrione @ 0.075 kg/ha (PoE) at 30 DAS, atrazine @ 0.75 kg/ha (PE) fb tembotrione @ 0.10 kg/ha (PoE) at 30 DAS. Pearl millet 'Pusa composite 443' was sown at the seed rate of 5 kg/ha at the spacing of 50  $cm \times 10$  cm on 16th July 2019 in ZT and CT plots. The full dose of  $P_2O_5$  (40 kg/ha),  $K_2O$  (40 kg/ha) and half dose of N (30 kg/ha) were applied basal at the time of sowing. Remaining N (30 kg/ha) was applied in 2 equal splits-25 and 50 DAS. Pre-emergence application of atrazine was done within 24 hours of sowing and post-emergence herbicides 2,4-D and tembotrione at 30 DAS. First hand-weeding was done manually at 30 DAS in respective plots of the treatment and the second was at 50 DAS.

Growth parameters and yield attributes of pearl millet were measured using standard methods. After threshing, cleaning, and drying the grain to a permissible moisture content of 9–10%, grain yield was calculated. The stover yield of pearl millet for each plot was worked out by deducting the grain weight from total biomass. The biomass was left for sun drying completely. The bundle weight of air-dry biomass was taken to record the biological yield. The harvest index was calculated by dividing economic yield with biological yield and expressing it in % values. Nitrogen (N), phosphorus (P) and potassium (K) contents were estimated by modified Kjeldahl method (Prasad *et al.*, 2006), vanadomolybdophosphoric acid yellow colour method (Jackson, 1973) and flame photometer method (Jackson, 1973) respectively. The energy coefficients for different parameters were derived using the formulae according to Demicran *et al.* (2006) and Lal *et al.* (2015). All the data obtained from the pearl millet crop were statistically analysed in the split-plot analysis as per the standard procedure.

The treatment with ZT + R 3 t/ha showed significantly higher values of yield attributes, viz. ears/m<sup>2</sup>, ear length, grain weight/ear, and 1,000-grain weight in pearl millet than the CT. However, this treatment was on par with the ZT plot (Table 1). Increased values of yield parameters may be attributed to lesser weed competition due to higher weed suppression and weed seed predation by the application of crop residues in zero tillage. Singh *et al.*, (2018) observed that, increasing soil moisture due to residue retention enhanced the growth and biomass production of crops, both directly and indirectly, by increasing the bio-availability and utilization of applied and endemic nutrients.

Among the weed-management practices, hand-weeding at 30 and 50 DAS resulted in a significantly higher number of ears/m<sup>2</sup>, ear length, grain weight/ear, and 1,000-grain weight over weedy check and application of atrazine @ 0.75 kg/ha (PE) and the values were statistically at par with atrazine 0.75 kg/ha (PE) *fb* 2,4-D 0.75 kg/ha (PoE). Preemergence application of atrazine @ 750 g/ha *fb* HW at 30 DAS ensued higher growth parameters and higher yield attributes which were due to weed-free condition for a longer period during the crop ontogeny by pre-emergence and post-emergence application of herbicides and thereby increasing the availability of growth resources to the crop as per Mishra *et al.*, (2017).

The treatment with ZT + R 3.0 t/ha was significantly superior concerning grain (2.4 t/ha) and stover yield (7.9 t/ ha). The increase in grain yield was 9.2 and 13.3% under ZT + R 3 t/ha over ZT and CT. Parameswari (2013) reported that, significant increase in grain and stover yields with zero tillage + residue 3 t/ha was attributed to increased growth and yield parameters owing to reduced weed competition, improving and maintaining soil moisture, regulating soil temperature, and increasing organic matter nutrients. Among different weed management, higher pearl millet grain and stover yields were obtained with 2 HW at 30 and 50 DAS. The increase in grain and stover yield was 34.8 and 34.2%, respectively, over weedy check with 2 HW at 30 and 50 DAS. However, because of little phytotoxic effect due to the visual symptoms of bleaching in

Treatment	Ears/m <sup>2</sup>	Ear/length (cm)	Grain weight/ear (g)	1,000-grain weight (g)	Grain yield (t/ha)	Stover yield (t/ha)	Harvest index (%)
Main Plot: Tillage	practices						
CT	29.9	21.7	18.5	7.2	2.08	6.70	23.7
ZT	32.0	22.6	19.7	7.6	2.18	7.16	23.3
ZT + R 3 t/ha	38.8	24.6	20.9	8.0	2.40	7.90	23.4
SEm±	0.7	0.56	0.36	0.13	0.04	0.18	0.51
CD (P=0.05)	2.7	2.26	1.48	0.53	0.18	0.72	NS
Subplot: Weed-man	agement pract	ices					
Ŵ	23.9	20.1	16.3	7.2	1.65	5.35	22.7
W <sub>2</sub>	40.3	25.1	22.3	8.1	2.53	8.13	23.8
Ŵ,	36.2	23.2	20.9	7.5	2.42	7.76	23.8
W,	28.7	21.4	17.5	7.5	2.09	6.72	23.7
W <sub>5</sub>	34.1	23.5	20.1	7.6	2.27	7.79	23.5
W	36.3	23.7	20.5	7.6	2.33	7.72	23.3
W <sub>2</sub>	35.4	23.5	20.3	7.5	2.29	7.33	23.4
ŚEm±	1.07	0.8	0.37	0.09	0.07	0.19	0.53
CD (P=0.05)	3.08	2.6	1.08	0.3	0.22	0.56	NS

Table 1. Pearl millet yield attributing characters and yield as affected by tillage and weed-management practices under conservation tillage

CT, Conventional tillage; ZT, zero tillage; ZT + R, zero tillage + residue;  $W_1$ , weedy check;  $W_2$ , hand-weeding at 30 and 50 days after sowing (DAS);  $W_3$ , pre-emergence (PE) application of atrazine @ 0.75 kg/ha *fb* post-emergence (PoE) application of 2, 4-D 0.75 kg/ha;  $W_4$ , PE application of atrazine @ 0.75 kg/ha;  $W_5$ , PE application of atrazine @ 0.75 kg/ha *fb* PoE application of tembotrione @ 0.05 kg/ha;  $W_6$ , PE application of atrazine @ 0.75 kg/ha *fb* PoE application of atrazine @ 0.75 kg/ha *fb* PoE application of tembotrione @ 0.075 kg/ha;  $W_7$ , PE application of atrazine @ 0.75 kg/ha *fb* PoE application of tembotrione @ 0.075 kg/ha;  $W_7$ , PE application of atrazine @ 0.75 kg/ha *fb* PoE application of tembotrione @ 0.10 kg/ha

crop leaves due to higher dose of tembotrione (0.10 kg/ha), grain yield was recorded 1.72% lower than its reduced dose (0.075 kg/ha). An increase of the grain and stover yield indicates that HW at 30 and 50 DAS, and a combination of pre- and post-emergence application of herbicides effectively controlled broad-spectrum weeds, which is of prime importance to achieve a higher yield of pearl millet in rainfed conditions. The harvest index (HI) of pearl millet did not show any significant difference due to tillage practices. However, ZT + R 3 t/ha and HW at 30 and 50 DAS showed the maximum HI which may be owing to the positive role of tillage and weed-management practice in partitioning from source to sink.

Tillage practices significantly influenced the consumptive use, WUE and soil temperature. Higher WUE (6.54 kg/ha-mm) was recorded in ZT + R 3 t/ha plots compared to CT (5.32 kg/ha-mm) plot (Table 2). The corresponding treatment also increased 18.65% water-use efficiency over conventional tillage. Total water input, i.e. effective rainfall (mm) + irrigation water applied (mm) + soil profile moisture contribution (mm), during pearl millet growing season was mostly contributed by rainfall. The total amount of water used in ZT + R plots was significantly lower (371.9 mm) than CT (388.0 mm). Johnson *et al.*, (2016) reported that, there was a significant improvement in storage of water in the soil profile and increase in water-use efficiency by leaving the crop residue on the soil surface. ZT + R 3 t/ha resulted in a maximum decrease in soil temperature recorded at 8 AM and 2 PM. The mean soil temperature was  $25.7^{\circ}$ C at 8 AM and  $35.2^{\circ}$ C at 2 PM in ZT + R 3 t/ha compared to  $27^{\circ}$ C and  $37.5^{\circ}$ C at 8 AM and 2 PM under CT. The decrease in soil temperature can be attributed to crop residue remaining on the soil surface in conservation tillage systems which decrease the rate of soil temperature change because surface residue increases the reflection of incident solar radiation (Li *et al.*, 2013). Stigter *et al.*, (2018) reported that mulch acts as a insulating barrier between the soil surface and atmosphere air, which changes the roughness of the soil-atmosphere boundary layer, as well as the dynamical thermal and moisture properties of the surface layer. Weed management treatments showed a notable difference in soil temperature, consumptive use and water-use efficiency in pearl millet.

Maximum temperature of soil (26.6°C at 8 AM and 36.7°C at 2 PM) and water-use efficiency (6.45 kg/ha-mm) were recorded under HW at 30 and 50 DAS. Weedy check resulted in significantly higher consumptive use of water (387.1 mm). Less consumptive use of water and increased water-use efficiency of pearl millet under hand-weeding could be ascribed to higher grain yield of pearl millet, which is the numerator in the water-use efficiency calculation formula.

The highest net energy gain was recorded under zero tillage, being 22.8 and 6.46% higher over ZT + R 3 t/ha and CT respectively (Table 2). Pearl millet crop planted under zero tillage resulted in consumption of lowest energy

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 Table 2.
 Soil temperature, consumptive use of water, water-use efficiency and energy of pearl millet as affected by tillage and weed-management practices under conservation tillage

Treatment	Soil temperature (8 am) °C	Soil temperature (2 pm) °C	Consumptive water use (mm)	Water-use efficiency (kg/ha-mm)	Net energy (MJ/ha)	Specific energy (MJ/kg)	Energy productivity (kg/MJ)	Energy- use efficiency
Main Plot Tillage	e practices							
СТ	27.0	37.5	388.0	5.32	106.744	4.15	0.20	13.7
ZT	26.5	36.8	384.4	5.61	114.117	3.77	0.27	15.3
ZT + R 3 t/ha	25.7	35.2	371.9	6.54	88.112	19.3	0.05	2.9
SEm±	0.08	0.08	7.96	0.18	1.987	0.34	0.03	0.3
CD (P=0.05)	0.33	0.34	NS	0.59	7,930	1.28	0.09	1.2
Subplot: Weed-ma	anagement prac	ctices			,			
Ŵ.	26.6	36.5	387.1	4.23	79,477	11.3	0.15	9.12
W	26.6	36.7	381.2	6.45	110,028	9.45	0.15	8.31
W	26.5	36.4	382.1	6.31	110,167	8.06	0.21	11.5
W	26.6	36.4	385.4	5.42	97,878	9.31	0.19	10.6
W.	26.3	36.5	383.3	6.23	111,046	8.52	0.21	11.9
W	26.2	36.5	382.0	6.11	106,538	8.31	0.21	11.4
W	26.2	36.4	381.3	6.10	105,941	8.48	0.21	11.6
SEm±	0.16	0.11	4.2	0.14	3.010	0.28	0.003	0.29
CD (P=0.05)	NS	NS	NS	0.46	8,642	0.81	0.009	0.83

CT, Conventional tillage; ZT, zero tillage; ZT + R, zero tillage + residue; W<sub>1</sub>, weedy check; W<sub>2</sub>, hand-weeding at 30 and 50 days after sowing (DAS); W<sub>3</sub>, pre-emergence (PE) application of atrazine @ 0.75 kg/ha *fb* post-emergence (PoE) application of 2, 4-D 0.75 kg/ha; W<sub>4</sub>, PE application of atrazine @ 0.75 kg/ha; W<sub>5</sub>, PE application of atrazine @ 0.75 kg/ha *fb* PoE application of tembotrione @ 0.05 kg/ha; W<sub>6</sub>, PE application of atrazine @ 0.75 kg/ha *fb* PoE application of atrazine @ 0.75 kg/ha *fb* PoE application of tembotrione @ 0.75 kg/ha *fb* PoE application of tembotrione @ 0.75 kg/ha *fb* PoE application of tembotrione @ 0.75 kg/ha *fb* PoE application of atrazine @ 0.75 kg/ha *fb* PoE application of tembotrione @ 0.075 kg/ha *fb* PoE application of tembotrione @ 0.10 kg/ha

(3.77 MJ/kg), maximum energy productivity (0.27 kg/MJ), and highest energy-use efficiency (15.3%), whereas ZT + R 3 t/ha showed the maximum energy consumption (19.3 MJ/kg), lowest energy productivity (0.05 kg/MJ) and energy-use efficiency (2.93%). The lower energy consumption, higher energy productivity, and energy-use efficiency with zero tillage might be ascribed to no use of energy in land preparation and residue use. Although the ZT + R 3 t/ha treatment recorded no energy consumption in the tillage operation, the use of residues increased energy consumption, resulting in reduced energy productivity and energyuse efficiency. Parihar et al., (2011) also reported lower energy productivity and energy-use efficiency with the use of residues in zero tillage compared to only zero tillage. Among weed-management options, atrazine 0.75 kg/ha (PE) fb tembotrione 0.05 kg/ha (PoE) recorded the highest net energy gain of 111,046 MJ/ha, which was on a par with atrazine 0.75 kg/ha (PE) fb 2,4-D 0.75 kg/ha (PoE) and HW at 30 and 50 DAS. However, the minimum energy consumption (8.06 MJ/kg) was recorded with atrazine 0.75 kg/ha (PE) fb 2,4-D 0.75 kg/ha (PoE), whereas the highest energy-use efficiency (11.9%) was reported with atrazine 0.75 kg/ha (PE) fb tembotrione 0.05 kg/ha (PoE).

Increase in net energy gain, energy productivity, and energy-use efficiency with the combination of pre- and post-emergence herbicides and 2 hand-weedings was owing to better weed control, growth and yield, nutrient uptake, and moisture use by pearl millet crop compared to the sole application of atrazine 0.75 kg/ha and weedy check.

It can be concluded from the study that, zero tillage + residue 3 t/ha could be a viable and economical option to conventional tillage, and among weed-management practices, 2 hand-weeding at 30 and 50 DAS along with the pre-emergence application of atrazine at the rate of 0.75 kg/ha for increased crop productivity, enhanced water and energy-use-efficiency of rainfed pearl millet under conservation agriculture of semi-arid tropics.

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