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Research Paper

Influence of tillage and residue-management practices and organic nutrition on performance of soybean (*Glycine max*) under conservation agriculture in semiarid ecology of India

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ABSTRACT

A field experiment was conducted during the rainy (*kharif*) season of 2020 and 2021 at the Chaudhary Charan Singh Haryana Agricultural University, Hisar to evaluate the impact of different tillage and residue-management practices (TRMPs) and organic nutrition on performance of soybean [*Glycine max* (L.) Merr.]. The experiment was laid out in a split-plot design with 3 replications. The treatment comprised 4 TRMPs in main plots and 5 organic nutrient management practices in subplot. The result showed that, application of zero tillage with residue (ZT + R) resulted in significantly higher number of branches/plant (9.65), pods/plant (69.2), seeds/pod (2.68), grain yield (1.63 t/ha) and gross return (₹ 87,480/ha) being statistically at par with conventional tillage with residue (CT + R) and superior to the other treatments. Significantly enhanced yield attributes i.e. branches/plant (9.12), pods/plant (69.8), seeds/pod (2.71) and grain yield (1.6 t/ha) were observed under application of recommended dose of fertilizer (RDF) through inorganic fertilizers followed by recommended dose of nitrogen through vermicompost (VC) + biofertilizer + cow urine (10%) + *Panchgavya* (5%) + *Jeevamrut* (500 litres/ha), recommended dose of nitrogen through farmyard manure (FYM) + biofertilizer + cow urine (10% foliar application at vegetative, panicle emergence and flowering stage) + *Panchgavya* (5% foliar application at vegetative, panicle emergence and flowering stage) + *Jeevamrut* (500 litres/ha foliar application at 30, 60 and 90 days after sowing (DAS). However, the maximum gross returns realized under N_5 (₹ 87,280/ha) followed by N_4. Hence, combined application of ZT + R along with N_5 organic package and followed by ZT + R along with N_4 organic package are better options for improving the yield attributes and productivity of soybean crop under conservation agriculture (CA) in semiarid ecology of India and similar agro-eco regions.

Key words: Conservation agriculture, Organic nutrition, Productivity, Tillage practices

Widespread degradation of soils and natural resources now pose a challenge for researchers/scientists to come out with an advanced natural resource-management practice for sustainable productivity and improved soil health (Bhattacharya *et al.,* 2020). Natural resource management has become a vital component for sustainable agriculture because of extensive resource degradation. Thus, the concept of conservation agriculture (CA) has slowly come out as an alternative to maintain soil health and agricultural sustainability. The CA has potential to change the physical, chemical and biological parameters of soil compared to conventional tillage (CT) systems (Sepat and Rana, 2013). The improved bio-physico-chemical soil quality in turn, affects the ecosystem services and sustainability of crop production system through counter balancing the climate variability with the help of increasing sink for carbon sequestration within the soil (Yadav *et al*., 2013). Managing agro-ecosystems for sustaining enhanced productivity, farm profitability and food security, along with protecting the environment and improving soil health, enhancing C sequestration and natural resource base are the characteristics of CA. To meet this challenge, environment unfriendly agricultural chemicals, such as fertilizers, have played a significant role in Green Revolution and even today, commonly recommended to outwit nutrient deficiencies of the soils (Kumar *et al.,* 2018). Imbalanced fertilizer use and mismanagement of crop residue via burning and removal from the field are still in practice under cereal-cereal cropping systems which cause soil and environmental

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pollution, nutrient mining, multi-nutrient deficiency, losses in soil bio-fertility, reduction in partial factor productivity, loss of agri-biodiversity, and ultimately, poor soil health and sub-optimal crop production. The disruption of microbial diversity and consequently the bio-fertility, due to inappropriate nutrient-management strategy, has become a concern for optimum soil health and plant growth. Considering these negative implications on agro-ecology, the need for reduced and balanced fertilizer applications along with crop diversification is being felt more essential than ever before (Kumar *et al.,* 2018). In this context, the role of naturally abundant but functionally unexplored microorganisms, such as nitrogen fixing, phosphorus and potash-solubilizing microbial inoculants along with their synergic integration with other organic sources of nutrients, such as bulky manures under a fertility augmentative legume crop, is crucial and offers a unique opportunity for balancing soil fertility, maintaining soil health, improving plant growth and profitable crop production in a sustainable way (Verma *et al.,* 2019; Verma *et al.,* 2019a). Since, poor soil-fertility management resulted in poor crop yield in Indo-Gangetic Plain (IGP) under low clay content and soil organic carbon due to irrational use of agro-chemicals, use of organic sources of nutrients in crop production can ensure a sustainably high level of crop productivity (Babu *et al.,* 2020). Keeping these in view, the present experiment was conducted to study the effect of different TRMPs and organic nutrition on yield attributes and yields of soybean under conservation agriculture in semiarid ecology of India.

MATERIALS AND METHODS

A field experiment was conducted during rainy (*kharif*) season of 2020 and 2021 at Research Farm of Agronomy, Chaudhary Charan Singh Haryana Agricultural University, Hisar (29° 08′57.4″ N and 75î 41′02.8″ E, 215.2 m above the mean sea-level). The average annual rainfall of about 143.5 mm was received during the crop-growing period. The average maximum 544.2 mm rainfall was recorded in July and no rainfall was observed in November. The average maximum average temperature (29.1°C) was registered in August and the minimum (7.0°C) in January. The average maximum relative humidity (91.7%) was noticed in July and the minimum in January (34.3%) (Fig. 1). The soil of experimental field was sandy loam, having bulk density 1.58 Mg/m^3, *p*H 7.7, electrical conductivity (0.33 dS/m), low soil organic carbon (0.32%) and available N (183.2 kg/ha), medium available P (14.0 kg/ha) and available K (281.7 kg/ha). The experiment comprised 20 treatment combinations in split-plot design which consisted of 4 treatments of tillage and residue management, viz. conventional tillage without residue (CT – R); conventional tillage with residue (CT + R); zero tillage without residue (ZT – R) and zero tillage with residue (ZT + R), in main plot and 5 treatments of organic nutrient management, viz. N_1, recommended dose of fertilizers (RDF); N_2, recommended dose of nitrogen (RDN) through FYM; N_3, RDN through vermicompost (VC); N_4, RDN through FYM + biofertilizer + cow urine 10% + *Panchgavya* 5% + *Jeevamrut* 500 litres/ha and N_5, RDN through VC + biofertilizer + cow urine 10% + *Panchgavya* 5% + *Jeevamrut* 500 litres/

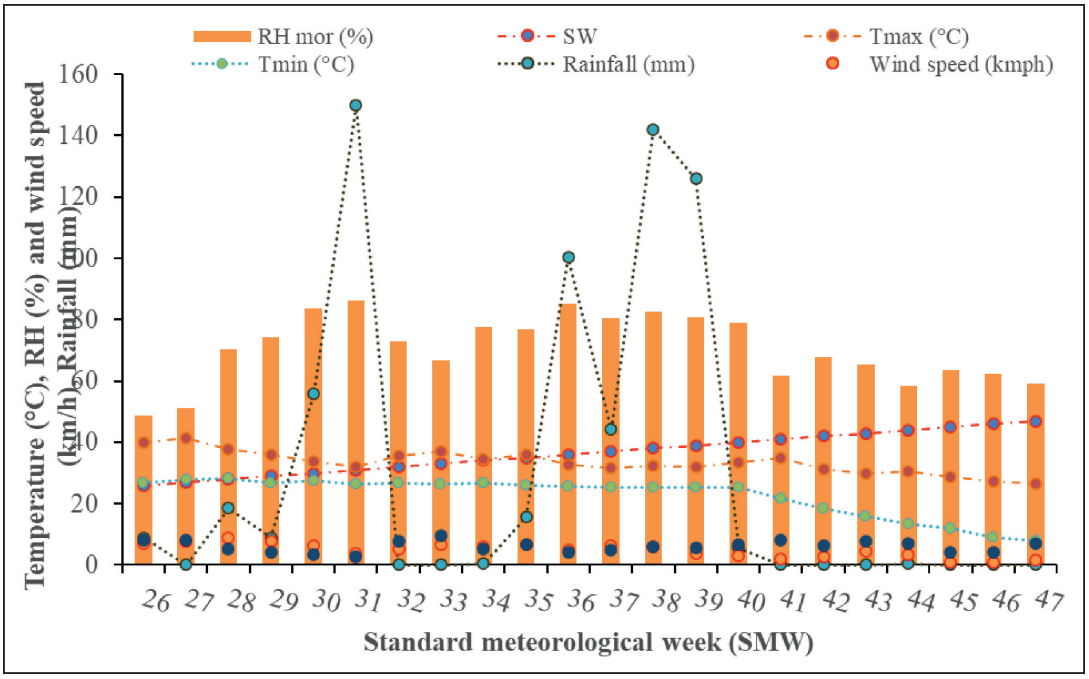

Fig. 1. Average weather parameters during 2020 and 2021

ha in subplots with 3 replications. The fertilizer nutrients (25: N, 60: P_2O_5 and K_2O: 40 kg/ha) were supplied through urea, diammonium phosphate and muriate of potash only in RDF treatment and in the other treatment supplied through organic bulky manures. Starter dose of nitrogen and full dose of phosphorus and potassium as per treatment were applied at sowing time. Seeds were treated with biofertilizer (20 g/kg seed) as per standard procedure and were sown after drying for 6 hours under shade. Soybean cultivar 'SL 958' was sown at row-to-row spacing of 35 cm and plant-to-plant spacing of 10 cm during the first week of July with a seed rate of 80 kg/ha. Standard crop-husbandry practices were followed during the experimentation. Observations on yield attributes and yield were recorded. The data collected on different parameters were subjected to statistical analysis under split-plot design by following the procedure of analysis of variance (SAS Software packages, SAS EG 4.3). Significance of difference between means was tested through 'F' test and the least significant difference (LSD) was worked out where variance ratio was found significant for treatment effect. The treatment effects were tested at 5% probability level for their significance.

RESULTS AND DISCUSSION

Yield attributes

The mean data of 2 years indicated that, tillage and residue-management practices (TRMPs) had significant ($P<0.05$) effect on yield attributes and yields of soybean. The number of branches/plant were significantly higher in ZT + R (9.65), being 18.4, 14.8 and 4.5% higher than that of ZT – R, CT – R and CT + R, respectively (Table 1). Similarly, number of pods/plant varied from 64.43 to 69.43 and found in order of ZT + R > CT + R > CT –R > ZT – R. The treatment ZT + R (2.69) outperformed other 3 TRMPs, ZT – R, CT – R and CT + R in terms of seeds/pod of soybean. However, effect of TRMPs was found non-significant effect on 1,000-seed weight. Average of 2 years data revealed that, the organic nutrient management practices (ONMPs) had significant effect on yield attributes of soybean. Significantly higher number of branches/plant was recorded in N_1 followed by N_5, N_4 and was lowest in N_2. Similarly, N_1 outperformed the other 4 $ONMP_S$, N_5, N_4, N_3 and N_2 in term number of pods/plants. The highest number of seeds/pod of soybean was recorded in $ONMP_S$, N_5 (2.71), which was 8.8, 7.3, 5.1 and 2.2% higher than other ONMPs, viz. N_2, N_3, N_4, and N_5, respectively.

The production capacity of different crops under CA is regulated by the complex interaction of management practices, microclimate and soil health (Singh *et al.,* 2016). Conservation agriculture (ZT/CT) with residue retention and inclusion of legumes has been reported to be productive, profitable, and efficient under rice and maize-based systems in the Asian subcontinent (Das *et al.,* 2020). The soybean productivity in term of yield attributes in the present study was higher under ZT + R than that under CT + R, CT – R and ZT – R during both the years. The soy-

Table 1. Effect of tillage and residue management practices and organic nutrition on yield attributes, yield and economics of soybean crop (2 years mean data)

Treatment	Branches/ plant	Pods/ plant	Seeds/ pod	1000-seed weight (g)	Grain yield (t/ha)	Stover yield (t/ha)	Biological yield (t/ha)	Harvest index	Gross return (×10³ ₹/ha)	Net return (×10³ ₹/ha)	Benefit : cost ratio
Tillage and residue-management practices											
CT – R	8.22	66.8	2.58	112.5	1.45	2.89	4.34	33.4	77.84	41.02	1.12
CT + R	9.22	68.4	2.67	113.6	1.53	3.05	4.58	33.4	82.18	44.11	1.17
ZT – R	7.87	64.4	2.50	110.9	1.33	2.71	4.04	33.0	71.45	39.64	1.25
ZT + R	9.65	69.2	2.69	114.3	1.63	3.27	4.91	33.2	87.48	53.62	1.62
SEm±	0.16	0.95	0.03	0.94	0.04	0.08	0.13	0.18	2.50	1.57	0.04
CD (P≤0.05)	0.54	3.28	0.09	NS	0.16	0.30	0.46	NS	8.65	4.72	0.13
Organic nutrient management packages											
N_1	9.12	69.8	2.71	113.7	1.63	3.25	4.88	33.4	73.76	38.27	1.08
N_2	8.37	64.4	2.47	111.6	1.33	2.65	3.99	33.3	74.57	44.60	1.50
N_3	8.51	66.2	2.51	112.4	1.41	2.81	4.22	33.4	78.90	44.14	1.28
N_4	8.67	67.4	2.57	113.0	1.50	3.02	4.53	33.2	84.18	48.83	1.40
N_5	9.04	68.2	2.62	113.5	1.55	3.17	4.73	32.9	87.28	47.14	1.19
SEm±	0.15	1.06	0.05	1.15	0.04	0.09	0.13	0.20	2.40	1.38	0.04
CD (P≤0.05)	0.47	3.05	0.16	NS	0.14	0.27	0.41	NS	6.91	4.12	0.12

CT – R, Conventional tillage without residue; CT + R, Conventional tillage with residue; ZT – R, Zero tillage without residue, ZT + R, Zero tillage with residue; N_1, Recommended dose of fertilizer (20: N, 60: P_2O_5 and 40 K_2O); N_2, Recommended dose of nitrogen through FYM; N_3, Recommended dose of nitrogen through vermicompost; N_4, Recommended dose of nitrogen through FYM + biofertilizer + cow urine 10% + *Panchgavya* 5% + *Jeevamrut* 500 litres/ha and N_5, Recommended dose of nitrogen through vermicompost + biofertilizer + cow urine 10% + *Panchgavya* 5% + *Jeevamrut* 500 litres/ha

bean attributes were higher under ZT + R than with ZT – R, CT – R and CT + R across the years and might be attributed due to the beneficial roles of higher soil organic matter and consistent soil environmental condition which favoured the growth and development of soybean crop as also reported by Verma *et al.,* 2019 in soybean wheat system. Excessive tillage in CT – R exposed the soil to runoff and nutrient loss during the grand-growth period of wheat results in lower yield when compared with ZT + R and CT + R (Nandan *et al.,* 2019). Furthermore, ZT + R provides favourable physical conditions for proper plant establishment at early growth stages to wheat crop which might have contributed to higher yield attributes. The organic nutrient management resulted in significantly ($P<0.05$) higher yield attributes, grain, stover and biological yields of soybean crop. Application of N_1, N_5 and N_4 treatment resulted in significantly higher yield grain and stover/straw yields of soybean over the other remaining treatments. However, gross returns were maximum under N_5, followed by N_4 and net returns were maximum in N_4, followed by N_5. The maximum benefit : cost ratio was observed in N_2, followed by N_4 treatment. An application of RDN through VC + biofertilizer + CU + *Panchgavya* + *Jeevamrut* under N_5 helped in improving soil physical properties and meeting the nutrient demand at peak growth period of soybean as compared to the other treatments (Das *et al.,* 2020).

Yield

The mean data of 2 years indicated that, tillage and residue-management practices (TRMPs) had significant effect on grain, stover and biological yields of soybean. Significantly higher grain yield of soybean was recorded in ZT + R (1.64 t/ha), which was 18.5, 11.2 and 6.2% higher than that of ZT – R, CT – R and CT + R, respectively. Similarly, stover yield of soybean varied from 2.71 to 3.27 t/ha and was found in order of ZT + R > CT + R > CT – R > ZT – R (Table 1). The ZT + R (4.91 t/ha) outperformed the other 3 TRMPs, ZT – R, CT – R and CT + R in term of biological yield of soybean. However, harvest index was found non-significant due to TRMPs. Average of 2 years data revealed that, the ONMPs had significant effect on grain, stover and biological yields of soybean. The statistically significant higher grain yield of soybean was recorded in N_1, followed by N_5, N_4 treatments being significantly higher over the other treatments. The lowest was in N_2 treatment. Similarly, treatment N_1 outperformed the other 4 $ONMP_S$ in term of stover yield of soybean (Table 1). Significantly highest biological yield of soybean was recorded with N_1 (4.89 t/ha), which was 18.3, 13.6, 7.3 and 3.2 % higher than N_2, N_3, N_4, and N_5 treatments, respectively.

The intricate combination of management strategies, microclimate, and soil health regulates the production potential of various crops under CA (Singh *et al.,* 2016). In the current study, soybean productivity in terms of grain yield was greater under ZT + R than under CT + R, CT – R, and ZT – R for both the years. Higher crop yield and better soil properties in rice – potato cropping system under ZT + R have been reported (Sarangi *et al*., 2020). The higher grain yield observed under ZT + R than ZT – R, CT – R and CT + R could be attributed to the beneficial role of higher soil organic matter and the consistent soil environmental conditions that favoured the growth and development of soybean. Our results confirm the findings of Verma *et al.* 2019 in the soybean – wheat system. When compared to ZT + R and CT + R, excessive tillage in CT – R exposed the soil to runoff and nutrient loss during the grand-growth period of wheat, leading to poorer yield (Nandan *et al.,* 2019). The ZT + R treatment creates favourable physical circumstances for proper plant establishment in soybean crop at early growth stages, which may have led to greater yield and yield parameters. The ONMPs showed considerable improvement in grain, stover and biological yields of soybean crop. The application of N_1, resulted in considerably larger grain and stover/straw yields of soybean than the other treatments owing to improvement in soil physical qualities and met the nutrient requirement during the peak growth period of soybean. Our results confirm the findings of Das *et al.,* (2020).

Economics

In general, cost of cultivation of soybean was higher across the tillage and residue-management practices in the second year as compared to the first year. Two-years mean data showed that, the total cost of cultivation of soybean among the TRMPs was high with CT + R, being higher by which was ₹1,250, 4,200 and 6,250/ha over CT – R, ZT + R and ZT – R treatments, respectively during both the years (Table 1). However, the maximum gross returns were obtained with ZT + R, ₹87,480/ha followed by CT + R, ₹82,180/ha, which were significantly higher over CT –R and ZT– R treatments. The net returns and benefit : cost ratio were maximum under ZT + R, which was significantly superior to CT + R, CT – R and ZT – R treatments during both years. In general, cost of cultivation of wheat was higher with N_5 and N_3 treatment in the second year compared to the first year. Among ONMPs, cost of cultivation was lower under N_2 and N_3 compared to the other treatments during study. Based on mean data, the maximum gross returns were registered with N_5 ₹87,280/ha followed by N_4 ₹84,180/ha being significantly higher than N_3, N_2 and N_1 treatments during the study. The treatments N_4 ₹48,430/ha gave higher net returns statistically at par with N_5 ₹47,140/ha treatment, which were significantly higher than other treatments. The benefit : cost ratio was

maximum under N_2 (1.50), followed by N_4 (1.40) and it was significantly higher than N_3, N_5 and N_1treatments.

Conservation tillage strategies had greater beneficial influence on soybean. The advantages of NT and residue retention were evident from the first year of research and continued to grow second year. Gross and net returns were substantially greater under ZT + R followed by CT + R than under ZT – R and CT – R. The greater gross returns and net returns under ZT + R were mostly attributable to higher soybean output compared to CT – R and ZT – R. Jat *et al.,* (2019) noticed a significant boost in system productivity of a maize-wheat cropping sequence under NT in northern Indo Gangetic Plain. Other researchers have reported similar results on an improvement in system production of intensive cropping systems using CT methods in conjunction with residue conservation (Jat *et al*., 2019; Nandan *et al.,* 2019). Boosted yield of soybean under ZT in conjunction with residue integration increased system economics. The gross return was 11.0% greater with ZT + R compared with CT – R. Similarly, under ZT + R, net return and benefit : cost ratio were 23.6 and 30.8% higher, respectively than CT – R. In the current study, the soybean with ZT+R/CT+R had ₹87,480 and 82,180/ha greater gross returns than CT – R. Better economic performance of rice-wheat and rice-maize systems under conservation tillage methods in the Northwestern Indo Gangetic Plain zone and the Eastern Gangetic Plains of India has been documented (Singh *et al.,* 2016). The gross returns were 35.9 and 12.3% greater under N_5 and N_3 than under N_1 owing to better soybean productivity and minimum support price at these levels. However, the net returns was 21.6 and 18.8% greater in N_4 and N_5 respectively, than N_1. The benefit : cost ratio was 28.0 and 22.8% higher in N_2 and N_4, respectively than N_1 because N_2 was less expensive than N_5 hence, benefit : cost ratio was somewhat greater. Higher gross returns and net return have also been documented with the use of FYM in various crops in comparable ecosystems our results confirm the findings of Das *et al*. (2020).

CONCLUSION

This study revealed that, the combined application of zero tillage with residue retention (ZT + R) and recommended dose of nitrogen through vermicompost + biofertilizer + cow urine 10% + *Panchgavya* 5% + *Jeevamrut* 500 litres/ha (N_5) and followed by zero tillage without residue retention (ZT + R) with recommended dose of nitrogen through FYM + biofertilizer + cow urine 10% + *Panchgavya* 5% + *Jeevamrut* 500 litres/ha (N_4) is a better option for improving the yield attributes and productivity of soybean crop under conservation agriculture in semiarid ecology of India and similar agro-ecoregions.

REFERENCES

Babu, S., Singh, R., Avasthe, R.K., Yadav, G.S., Das, A., Singh, V.K., Mohapatra, K.P., Rathore, S.S., Chandra, P. and Kumar, A. 2020. Impact of land configuration and organic nutrient management on productivity, quality and soil properties under baby corn in Eastern Himalayas. *Scientific Report* **10**(1): 1–14 .

Bhattacharya, P., Maity, P.P., Mowrer, J., Maity, A., Ray, M., Das, S., Chakrabarti, B., Tridiv Ghosh, T. and Krishnan, P. 2020. Assessment of soil health parameters and application of the sustainability index to fields under conservation agriculture for 3, 6, and 9 years in India. *Heliyon* **6**(12): e05640.

Das, A., Layek, J., Ramkrushna, G.I., Basavaraj, S., Lal, R., Krishnappa, R., Yadav, G.S., Babu, S. and Ngachan, S.V. 2020. Conservation tillage and residue management improves soil properties under an upland rice–rapeseed system in subtropical Eastern Himalayas. *Land Degradation and Development*, **31**(14): 1,775–1,791.

Jat, R.K., Singh, R.G., Kumar, M., Jat, M.L., Parihar, C.M., Bijarniya, D., Sutaliya, J.M., Jat, M.K., Parihar, M.D., Kakraliyad, S.K. and Gupta, R.K. 2019. Ten years of conservation agriculture in a rice–maize rotation of Eastern Gangetic Plains of India: Yield trends, water productivity and economic profitability. *Field Crops Research,* **232**: 1–10.

Kumar, R., Makarana, G., Mishra, J.S., Choudhary, A.K., Hans, H., Biswas, A.K. and Kumar, U. 2021. Performance of promising lentil (*Lens culanaris*) cultivars under zero-till condition for sustainable intensification of rice (*Oryza sativa*)–fallows in eastern India. *Indian Journal of Agronomy,* **66**(4): 444–448.

Kumar, S., Dhar, S., Barthakur, S., Chandrakala, M., Meena, S.K.L. and Meena, L. 2018. Effect of integrated potassium management on soil biological properties and yields of corn under corn-wheat cropping system. *International Journal of Current Microbiology and Applied Sciences,* **7**: 1,855–1,866.

Nandan, R., Singh, V., Singh, S.S., Kumar, V., Hazra, K.K., Nath, C.P., Poonia, S., Malik, R.K., Bhattacharyya, R. and McDonald, A. 2019. Impact of conservation tillage in rice–based cropping systems on soil aggregation, carbon pools and nutrients. *Geoderma,* **340**: 104–114.

Sepat, S. and Rana, D.S. 2013. Effect of double no-till and permanent raised beds on productivity, profitability and physical properties of soil in maize (*Zea mays*)–wheat (*Triticum aestivum*) cropping system under Indo-Gangetic plains of India. *Indian Journal of Agronomy* **58**(4): 469–473.

Sarangi, S.K., Maji, B., Sharma, P.C., Digar, S., Mahanta, K.K., Burman, D., Mandal, U.K., Mandal, S. and Mainuddin, M. 2020. Potato (*Solanum tuberosum* L.) cultivation by zero tillage and paddy straw mulching in the saline soils of the Ganges Delta. *Potato Research* **64**(2): 277–305.

Singh, R., Babu, S., Avasthe, R.K., Yadav, G.S. and Rajkhowa, D.J. 2016. Productivity, profitability and energy dynamics of rice (*Oryza sativa*) under tillage and organic nitrogen management practices in rice–vegetable pea (*Pisum sativum*) cropping system of Sikkim Himalayas. *Indian Journal of Agricultural Sciences* **86**(3): 326–330.

Verma, G., Yadav, D.D., Gupta, G., Sharma, V.K., Kumar, A., Singh, R.K. and Upadhyay P.K. 2019. Effect of fertility levels and biofertilizers on agro-physiological performance,

productivity and quality of chickpea (*Cicer arietinum*). *Indian Journal of Agricultural Sciences* **89**(9): 1,482–1,486.

Verma, G., Yadav, D.D., Kumar, A., Gupta, G., Sharma, V.K., Upadhyay, P.K. and Singh, S. 2019a. Effect of fertility levels and biofertilizers on the chemical and biological properties of soil under late sown chickpea [*Cicer arietinum* L.]. *Annals of Agricultural Research* **40(**1): 57–61.

Yadav, S.K., Babu, S., Singh, Y. Yadav, M.K., Yadav, G.S., Pal, S., Singh, R., and Singh, K. 2013. Effect of organic sources of nutrients on yield, nutrient uptake and soil biological properties of rice (*Oryza sativa*)-based cropping systems. *Indian Journal of Agronomy* **58**(3): 271–276.