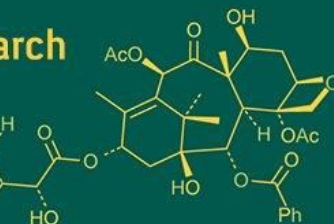
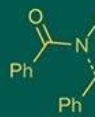


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Impact of maize-mustard cropping system on physical and chemical properties of soil in the northern hills region of Chhattisgarh

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Abstract

The present study entitled “Impact of maize-mustard cropping system on physical and chemical properties of soil in the northern hills region of Chhattisgarh” was conducted during the Kharif and Rabi seasons of 2022-23 and 2023-24 at Ambikapur, Chhattisgarh. The soil was sandy loam, acidic (pH 5.5), medium in organic carbon, low in available nitrogen, medium in phosphorus, and high in potassium. The experiment comprised twelve treatment combinations involving four residue management practices and three nutrient management levels. Maize (cv. NK 30) and mustard (cv. Chhattisgarh Sarson-1) were grown under recommended agronomic practices.

Results indicated that residue incorporation with microbial consortium significantly improved soil properties, including pH, organic carbon, and availability of macro-and micronutrients. This treatment performed comparably with residue incorporation alone and zero tillage with residue retention and microbial consortium application. Among nutrient levels, 100% RDF of NPK recorded the highest nutrient availability, while 75% RDF of NPK combined with 5 t FYM ha⁻¹ resulted in maximum organic carbon content. The study concludes that integrated residue and nutrient management enhances soil health and ensures sustainability of the maize-mustard cropping system.

Keywords: Residue management, soil fertility management, physical and chemical properties of soil, maize-mustard cropping system

1. Introduction

Maize (*Zea mays* L.) crop regarded as a queen of cereals occupies pride place among rainy (*Kharif*) season crops in India and contributing around 24% of total cereal production (Sinha, 2018) [15]. It is the crop which has great relevance as staple crop, significant yield potential and third most important cereal grain in the world after wheat and rice. Maize has the origination from the Guatemala and southern part of the Mexico. Maize assumes to have worldwide significance as a source of food, feed and diverse industrial products (Prasanna *et al.*, 2020) [15]. It is widely grown as the major crop throughout the world across a wide range of Agro-climates and diverse ecological zones.

In world, total area under the maize was 197.2 m ha and the total production was 1148.48 million tons with an average yield of about 5.82 tons ha⁻¹ (FAOSTAT, 2020) [3]. Seventy per cent of the world's production is being produced in countries of China, Brazil, Mexico and the United States of America. India has 5 per cent of maize acreage and contributes 2 per cent of world production (Tripathi *et al.*, 2011) [23]. In India, maize occupies an area of about 9.72 million hectare and the production was 28.64 metric tonnes with average yield of 2945 kg ha⁻¹. The major maize-growing states in India are Andhra Pradesh, Karnataka, Rajasthan, Maharashtra, Bihar, Uttar Pradesh, Madhya Pradesh, Chhattisgarh, Himachal Pradesh etc. These regions contribute more than 80 % of the nation's total maize production. In the state of Chhattisgarh it has an area about 206.63 thousand ha with productivity of 2789 kg ha⁻¹ during 2019-20.

Nutrient management is the most important factor in maize-mustard cropping system as being both the crops are exhaustive feeders of plant nutrients and following this system leads to the removal of the nutrients in the significant amount that cannot be sufficed by proper fertilizer and manure application which ultimately leads to the decline in the fertility of soil and the production of the system is greatly affected.

It is generally necessary to use chemical fertilizers in conjunction with organic manure to increase the soil health under continuous farming. The desired levels of crop output cannot be maintained by chemical fertilizers alone (Namdeo *et al.*, 2021) ^[9].

In-situ incorporation of high C:N ratio cereal straw immediately before planting of the next crop leads to immobilization of mineral N and lower crop yields due to N deficiency. Crops that have been harvested and threshed, the left-out part of the plants after this process are known as the crop residues. The open field burning of crop residues is a major contributor to air pollution (particulates, smoke, greenhouse gases), and human respiratory ailments. Crop residue burning influences human health and global climate change. It results in a loss of organic matter, N and S, and partial loss of P (20%) and K (25%). Adverse effects on soil and environment quality from burning could be addressed by promoting the practice of retaining crop residues on the field. This requires development and promotion of a zero till (ZT) machine that could seed crops into a layer of crop residues thus, avoiding the harmful effects of burning (Sidhu *et al.*, 2007) ^[20]. Surface residue retention provides multiple benefits, including soil moisture conservation, suppression of weeds, increase in the availability of plant nutrients, increase in soil enzyme activities, and improvement in soil organic matter and soil structure (Bera *et al.*, 2017) ^[2].

Crop residue improves the soil fertility that substantially reduces the requirements of fertilizer N and increase crop yield. Physical and chemical condition of the soil also being maintained by the crop residues even management and improvement of the ecological balance is feasible by this crop residues. The main obstacles in the productivity of crops include soils with low levels of organic matter, water holding capacity, and crust formation. As the cost of chemical fertilizers increasing and also with aim of improving the health of soil, the role of organic material came out to be more significant as it recognized as major part in the sustainable production. The organic matter or crop residue helps to recycle the nutrients to correct their deficiencies. Studies indicated that use of organic sources can help to maintain a better N:P ratio and higher yield.

Zero tillage is preferred in mustard as it conserves more moisture in the soil profile during early growth period. Subsequent release of conserved soil moisture regulates proper plant water status, soil temperature, lower soil mechanical resistance, leading to better root growth and

higher grain yield of mustard (Rathore *et al.*, 1999) ^[17]. If correctly managed, adding crop residue to the soil not only enhances the physical, chemical, and biological characteristics of the soil but also serves as a significant source of nutrients for crop productivity. In order to maximize the production, proper crop residues management technique as well as the proper management of nutrient is important.

2. Materials and Methods

The investigation titled “Impact of maize-mustard cropping system on physical and chemical properties of soil in the northern hills region of Chhattisgarh” was carried out during the *kharif* and *rabi* seasons of 2022-23 and 2023-24. This chapter meticulously outlines the materials employed, the procedural steps taken, and the techniques applied throughout the study, taking into account the diverse climatic conditions prevailing at the experimental site. The documentation of these details has been thorough, encompassing all the variations in climate during the experiment.

2.1 Location of the experimental site

Field experiment was conducted during *kharif* and *rabi* seasons of 2022-23 and 2023-24 at the Research Farm, Raj Mohini Devi College of Agriculture & Research Station, Ambikapur (Chhattisgarh), which is situated at 23°10' N latitude, 83°15' E longitude with an altitude of 623 meters above mean sea level. Ambikapur falls under Northern Hill Region of Chhattisgarh.

2.2 Soil characteristics of the experimental site

Soil acts as the crucial and essential medium for plant growth. Soil fertility and productivity are the major factors for the growth and development of the plant. So, an effort was made to evaluate the physical and chemical properties of soil of the experimental field. To examine the original fertility grade of the field, ten composite soil samples were collected randomly from the experimental site upto 15 cm depth with the help of soil auger before sowing and were analyzed for various physico-chemical properties. and are furnished in Table 1 along with methods employed. The soil of experimental field was sandy-loam in texture known as *Inseptsols*. The soil was acidic in reaction, medium in organic carbon and low in available nitrogen, medium in available phosphorus and high in available potassium.

Table 1: Physio-chemical properties of the soil of the experimental field

S. No.	Particulars	Values		Rating	Method used
		2022-23	2023-24		
Physical-Mechanical composition					
1.	Sand (%)	60.3		Sandy-loam (Inseptsols)	International pipette method (Black, 1965)
2.	Silt (%)	14.9			
3.	Clay (%)	23.4			
Chemical composition					
1.	Organic carbon (%)	0.50	0.56	Medium	Walkley and Black’s rapid titration method (Black,1965)
2.	Available N (kg ha ⁻¹)	234.1	218.5	Low	Alkaline permanganate method (Subbiah and Asija, 1956) ^[21]
3.	Available P ₂ O ₅ (kg ha ⁻¹)	12.9	12.8	Medium	Olsen’s method (Jackson,1973)
4.	Available K ₂ O (kg ha ⁻¹)	244.3	238.6	Medium	Flame photometric method (Jackson, 1973)
5.	pH (1:2.5::Soil: water)	5.5	5.5	Acidic	Glass electrode pH meter (Piper, 1967) ^[14]
6.	Electrical conductivity (dSm ⁻¹)	0.27	0.27	Normal	Solubridge conductivity method (Black, 1965)

3. Results and Discussion

3.1 Results

Data pertaining to soil chemical properties *viz.*, pH, organic carbon, available nitrogen, available phosphorus, available potassium and concentration of micronutrients (zinc, iron, manganese and copper) were analyzed at initial and harvest of mustard crop as influenced by different crop residue and nutrient management practices, and presented in Table 2 to Table 3.

3.1.1 pH

pH of soil was found to be increased in comparison to initial and differed significantly due to various treatments as presented in Table 2, during both the years of investigation as well as in mean.

3.1.2 Organic carbon (%)

The organic carbon content of soil increased compared to the initial levels and showed significant variation due to different treatments, as shown in Table 3, over both years of the study and on mean basis.

3.1.3 Available nitrogen (kg ha^{-1})

Available nitrogen in soil differed significantly due to various treatments and found to be increased as compared to initial N levels as presented in Table 3, during both the years of investigation as well as in mean.

3.1.4 Available phosphorus (kg ha^{-1})

Available phosphorus varied significantly from treatment-to-treatment during both the years of investigations and on mean basis (Table 3). It was increased as compared to initial in all of the treatments during both the years and on mean basis.

3.1.5 Available potassium (kg ha^{-1})

As per data presented in Table 3, available potassium had significant differences among various treatments. Available potassium in soil was increased as compared to initial in all the treatments during both the years and on mean basis.

3.1.6 Concentration of zinc (ppm)

The Zn content in soil increased compared to the initial levels and showed significant variation due to different treatments, as shown in Table 4, over both years of the study and on mean basis.

3.1.7 Concentration of iron (ppm)

Fe content in soil differed significantly due to various treatments and found to be increased as compared to initial Fe levels as presented in Table 4, during both the years of investigation as well as in mean.

3.1.8 Concentration of manganese (ppm)

Mn content of soil varied significantly from treatment-to-treatment during both the years of investigation and on

mean basis (Table 5). It was increased as compared to initial in all of the treatments during both the years and on mean basis.

3.1.9 Concentration of copper (ppm)

As per data presented in Table 4, Cu content of soil had significant differences among various treatments. Also, it was increased as compared to initial in all the treatments.

3.2 Discussion on nutrient status of soil

Study reveals that, the overall soil quality including pH, organic carbon content, available nitrogen, phosphorus and potassium, and micronutrient (*i.e.*, zinc, iron, manganese and copper) concentration were improved with the treatment crop residue incorporation and microbial consortium spray, comparable to residue incorporation alone and zero-tillage with residue retention and microbial consortium spray. While, conventional tillage proved inferior. The improvement in overall soil quality was observed with residue incorporation and microbial consortium spray, either alone or in combination with zero-tillage, can be attributed to several scientific factors.

In contrast, conventional tillage disrupts soil structure, accelerates organic matter decomposition, and diminishes microbial diversity and activity, leading to reduced nutrient availability and overall soil health degradation over time. Mitra and Mandal (2012) [7] further stated that the application of organic and inorganic nutrients along with proper moisture conservation practices can enhance the yields maintaining a good soil health. Saha and Ghosh (2013) [4], Noor *et al.* (2021) [10] and Pathak *et al.* (2015) [12] also reported the similar findings. Suryavanshi *et al.* (2018) [22] similarly found that when no residue was added, conventional tillage reduced soil fertility and productivity than the zero-tillage.

From the study, it was revealed that in terms of soil characteristics after crop harvesting *viz.*, pH, available nitrogen, phosphorus and potassium, and micronutrient (*i.e.*, zinc, iron, manganese and copper) concentration treatment 100% RDF showed superior outcome, followed by 100% RDN and P and 50% RDK, while regarding organic carbon content treatment 75 % RDF of NPK + 5 t FYM ha^{-1} proved to be the best. The superior outcomes observed with 100% RDF in terms of soil characteristics such as pH, nutrient availability (N, P, K) and micronutrient concentrations (zinc, iron, manganese, copper) can be attributed to several factors. Firstly, adequate application of RDF ensures that crops receive optimal amounts of essential nutrients necessary for their growth and development. This balanced nutrient supply promotes healthy root systems and vigorous plant growth, which in turn enhances nutrient uptake efficiency and reduces nutrient losses from the soil. Furthermore, the balanced supply of nutrients supports beneficial soil microbial activity, crucial for nutrient cycling and organic matter decomposition, thereby improving soil structure and fertility over time.

Table 2: Physicochemical properties of soil as influenced by crop residue and nutrient management in maize-mustard cropping system

Treatment		pH				Organic carbon (%)			
		Initial	2022-23	2023-24	Mean	Initial	2022-23	2023-24	Mean
Crop residue management									
M ₁ :	Residue removal	5.36	5.31	5.41	5.36	0.450	0.491	0.552	0.522
M ₂ :	Residue incorporation	5.33	5.88	5.87	5.87	0.445	0.533	0.598	0.565
M ₃ :	Residue incorporation + spray of microbial consortium	5.57	5.97	5.90	5.93	0.446	0.549	0.607	0.578
M ₄ :	Zero-tillage + residue retention and spray of microbial consortium	5.48	5.61	5.74	5.68	0.443	0.522	0.585	0.553
	SEm ±	0.05	0.10	0.08	0.09	0.006	0.007	0.008	0.008
	CD (P = 0.05)	NS	0.36	0.26	0.31	NS	0.027	0.030	0.029
Nutrient management									
N ₁ :	100%RDF	5.50	6.25	6.08	6.16	0.439	0.520	0.585	0.553
N ₂ :	100% RDN and P and 50% RDK	5.43	5.63	5.68	5.65	0.438	0.482	0.544	0.513
N ₃ :	75 % RDF of NPK + 5 t FYM ha ⁻¹	5.38	5.19	5.44	5.31	0.462	0.569	0.627	0.598
	SEm ±	0.12	0.09	0.06	0.07	0.0054	0.006	0.007	0.006
	CD (P = 0.05)	NS	0.35	0.23	0.28	0.0211	0.023	0.030	0.026
	Interaction	NS	NS	NS	NS	NS	NS	NS	NS

Table 3: Availability of primary soil nutrients as influenced by crop residue and nutrient management in maize-mustard cropping system

Treatment		Available Nitrogen (kg ha ⁻¹)				Available Phosphorus (kg ha ⁻¹)				Available Potassium (kg ha ⁻¹)			
		Initial	2022-23	2023-24	Mean	Initial	2022-23	2023-24	Mean	Initial	2022-23	2023-24	Mean
Crop residue management													
M ₁ :	Residue removal	212.5	214.0	225.1	219.6	10.77	11.95	12.25	12.10	210.5	221.9	232.8	227.4
M ₂ :	Residue incorporation	204.0	239.1	239.6	239.4	10.54	13.14	13.67	13.41	214.8	259.8	266.6	263.2
M ₃ :	Residue incorporation + spray of microbial consortium	213.8	243.3	245.8	244.5	10.54	13.44	14.14	13.79	214.7	270.5	284.0	277.2
M ₄ :	Zero-tillage + residue retention and spray of microbial consortium	210.8	230.8	235.4	233.1	10.47	12.74	13.25	12.99	210.7	250.1	257.6	253.8
	SEm ±	2.84	4.59	3.90	4.20	0.23	0.30	0.24	0.25	3.93	6.07	8.04	6.93
	CD (P = 0.05)	NS	15.90	13.48	14.54	NS	1.02	0.84	0.87	NS	21.01	27.83	23.98
Nutrient management													
N ₁ :	100%RDF	207.7	248.3	250.1	249.2	10.71	13.71	14.26	13.99	213.6	286.6	296.9	291.8
N ₂ :	100% RDN and P and 50% RDK	211.5	236.4	240.7	238.5	10.77	12.82	13.47	13.14	209.5	248.6	256.4	252.5
N ₃ :	75 % RDF of NPK + 5 t FYM ha ⁻¹	211.5	210.7	218.7	214.7	10.27	11.92	12.25	12.08	214.9	216.5	227.5	222.0
	SEm ±	2.37	4.50	4.20	4.33	0.13	0.24	0.23	0.23	3.75	4.63	7.41	5.99
	CD (P = 0.05)	NS	17.67	16.50	17.02	NS	0.92	0.91	0.89	NS	18.18	29.09	23.53
	Interaction	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS

Table 4: Concentration of soil micronutrients as influenced by crop residue and nutrient management in maize-mustard cropping system

Treatment		Soil micronutrients							
		Zinc (ppm)				Iron (ppm)			
		Initial	2022-23	2023-24	Mean	Initial	2022-23	2023-24	Mean
Crop residue management									
M ₁ :	Residue removal	0.517	0.484	0.523	0.504	13.87	14.33	15.80	15.07
M ₂ :	Residue incorporation	0.503	0.540	0.560	0.550	13.00	16.47	17.43	16.95
M ₃ :	Residue incorporation + spray of microbial consortium	0.507	0.570	0.577	0.573	13.57	17.53	18.00	17.77
M ₄ :	Zero-tillage + residue retention and spray of microbial consortium	0.503	0.513	0.553	0.533	13.53	15.94	16.70	16.32
	SEm ±	0.008	0.012	0.010	0.011	0.19	0.48	0.38	0.43
	CD (P = 0.05)	NS	0.043	0.035	0.038	NS	1.67	1.31	1.47
Nutrient management									
N ₁ :	100%RDF	0.510	0.590	0.588	0.589	13.45	18.13	18.78	18.45
N ₂ :	100% RDN and P and 50% RDK	0.518	0.533	0.553	0.543	13.48	15.95	16.85	16.40
N ₃ :	75 % RDF of NPK + 5 t FYM ha ⁻¹	0.495	0.458	0.520	0.489	13.55	14.13	15.33	14.73
	SEm ±	0.005	0.011	0.009	0.010	0.14	0.29	0.31	0.28
	CD (P = 0.05)	NS	0.044	0.034	0.039	NS	1.13	1.21	1.09
	Interaction	NS	NS	NS	NS	NS	NS	NS	NS

Table 5: Concentration of soil micronutrients as influenced by crop residue and nutrient management in maize-mustard cropping system

Treatment		Soil micronutrients							
		Manganese (ppm)				Copper (ppm)			
		Initial	2022-23	2023-24	Mean	Initial	2022-23	2023-24	Mean
Crop residue management									
M1:	Residue removal	20.53	22.00	22.70	22.35	0.39	0.46	0.50	0.48
M2:	Residue incorporation	20.77	25.30	25.23	25.27	0.38	0.54	0.56	0.55
M3:	Residue incorporation + spray of microbial consortium	20.57	26.27	27.07	26.67	0.43	0.55	0.58	0.57
M4:	Zero-tillage + residue retention and spray of microbial consortium	19.87	24.00	24.67	24.33	0.40	0.51	0.53	0.52
	SEm ±	0.28	0.70	0.76	0.70	0.01	0.01	0.01	0.01
	CD (P = 0.05)	NS	2.41	2.62	2.41	NS	0.04	0.05	0.04
Nutrient management									
N1:	100%RDF	20.08	27.13	27.88	27.50	0.40	0.57	0.59	0.58
N2:	100% RDN and P and 50% RDK	20.35	25.10	24.30	24.70	0.41	0.52	0.54	0.53
N3:	75 % RDF of NPK + 5 t FYM ha ⁻¹	20.88	20.95	22.58	21.76	0.39	0.46	0.50	0.48
	SEm ±	0.21	0.61	0.77	0.67	0.01	0.01	0.01	0.01
	CD (P = 0.05)	NS	2.41	3.01	2.64	NS	0.03	0.04	0.03
	Interaction	NS	NS	NS	NS	NS	NS	NS	NS

4. Summary and Conclusion

Overall soil quality, including pH, organic carbon content and levels of available nitrogen, phosphorus, potassium and micronutrients (zinc, iron, manganese and copper) was improved with the treatment of residue incorporation and microbial consortium spray. These improvements were comparable to those achieved with residue incorporation alone and zero-tillage with residue retention and microbial consortium spray. Further, the treatment with 100% RDF showed the best results regarding pH, nitrogen, phosphorus, potassium availability, and micronutrients concentration, followed by 100% RDN and P and 50% RDK. For organic carbon content, the treatment of 75% RDF of NPK combined with 5 t FYM ha⁻¹ was found to be the most effective.

References

- Azzez JO, Adetunji MT, Adebun U. Effect of residue burning and fertilizer application on soil nutrient dynamics and dry grain yield of maize (*Zea mays* L.) in an Alfisol. *Nig J Soil Sci.* 2007;17:71-80.
- Bera T, Sharma S, Thind HS, Singh Y, Sidhu HS, Jat ML. Soil biochemical changes at different wheat growth stages in response to conservation agriculture practices in rice-wheat system of north-western India. *Soil Res.* 2017;56:91-104.
- FAOSTAT. Food and Agriculture Organization of the United Nations; 2020.
- Ghos PK, Das A, Saha R, Tomar JMS. Improving mustard yield through in situ soil moisture conservation and conservation tillage in foothills of Meghalaya. *Indian J Soil Conserv.* 2010;38(3):184-187.
- Hati KM, Chaudhary RS, Mandal KG, Bandyopadhyay KK, Singh RK, Sinha NK, *et al.* Effects of tillage, residue and fertilizer nitrogen on crop yields and soil physical properties under soybean-wheat rotation in Vertisols of Central India. *Agric Res.* 2015. doi:10.1007/s40003-014-0141-7.
- Kumar K, Goh KM. Crop residue and management practices: Effects on soil quality, soil nitrogen dynamics, crop yield and nitrogen recovery. *Adv Agron.* 1999;68:197-319.
- Mitra B, Mandal B. Effect of nutrient management and straw mulching on crop yield, uptake and soil fertility in rapeseed (*Brassica campestris*)-greengram (*Vigna radiata*)-rice (*Oryza sativa*) cropping system under Gangetic plains of India. *Arch Agron Soil Sci.* 2012;58(2):213-222.
- Mucheru-Muna M, Mugendi D, Pypers P, Mugwe J, Kung'u J, Vanlauwe B, *et al.* Enhancing maize productivity and profitability using organic inputs and mineral fertilizer in central Kenya smallholder farms. *Exp Agric.* 2014;50(2):250-269.
- Namdeo S, Kumar P, Soni V. Effect of integrated nutrient management on yield and quality of Indian mustard (*Brassica juncea* L.). *Int J Creat Res Thoughts.* 2021;9(3):2320-2882.
- Noor MA, Nawaz MM, Ma W, Zhao M. Wheat straw mulch improves summer maize productivity and soil properties. *Ital J Agron.* 2021;16:1623.
- Olsen SR, Cole CV, Watanabe FS, Dean LA. Estimation of available phosphorus in soils by extraction with sodium carbonate. *USDA Circ.* 1954;939:1-9.
- Pathak DV, Gaur RK, Kumar P, Yadav SS. Effect of green manuring and residue incorporation on soil properties and seed yield of rapeseed mustard. *Int J Farm Sci.* 2015;5(4):1-8.
- Piper CS. Soil and plant analysis. Indian ed. Bombay: Hans Publishers; 1966. p. 19-136.
- Piper CS. Soil plant analysis. Bombay: Hans Publishers; 1967.
- Prasanna BM, Palacios-Rojas N, Hossain F, Muthusamy V, Menkir A. Molecular breeding for nutritionally enriched maize: status and prospects. *Front Genet.* 2020;10:1392.
- Rathore SS, Babu S, Shekhawat K, Singh VK, Upadhyay PK, Singh RK, *et al.* Oilseed *Brassica* species diversification and crop geometry influence productivity, economics and environmental footprints under semi-arid regions. *Sustainability.* 2022;14(4):2230.
- Rathore AL, Pal AR, Sahu KK. Tillage and mulching effects on water use, root growth and yield of rainfed mustard and chickpea grown after lowland rice. *J Sci Food Agric.* 1999;78(2):149-161.
- Rathore AL, Pal AR, Sahu KK. Tillage and mulching effects on water use, root growth and yield of rainfed mustard and chickpea grown after lowland rice. *J Sci Food Agric.* 1998;78:149-161.
- Shekhawat K, Rathore SS, Premi OP, Kandpal B, Chauhan JS. Advances in agronomic management of

- Indian mustard (*Brassica juncea* (L.) Czernj. Cosson): An overview. Int J Agric. 2012;1-14.
20. Sidhu HS, Singh M, Humphreys E, Singh Y, Singh B, Dhillon SS, *et al.* The Happy Seeder enables direct drilling of wheat into rice stubble. Aust J Exp Agric. 2007;47:844-854.
21. Subbiah BV, Asija GL. A rapid procedure for estimation of available nitrogen in soils. Curr Sci. 1956;25:259-266.
22. Suryavanshi T, Sharma AR, Nandeha KL, Lal S, Porte SS. Effect of tillage, residue and weed management on soil properties and crop productivity in greengram (*Vigna radiata* L.) under conservation agriculture. J Pharmacogn Phytochem. 2018;SP1:2022-2026.
23. Tripathi KK, Warriar R, Govila OP, Ahuja V. Biology of *Zea mays* (maize). New Delhi: Department of Biotechnology, Government of India; 2011.
24. Walkley A, Black CA. An examination of the Degtjareff method for determining soil organic matter and a proposed modification of the chromic acid titration method. Soil Sci. 1934;37:29-38.