Indian Journal of Agricultural Sciences **91** (1): 137–41, January 2021/Article
https://doi.org/10.56093/ijas.v91i1.110949

Impact of long-term sludge application on yield, nutrient uptake and profitability of maize (*Zea mays*)

ANIL KUMAR VERMA, MAHESH C MEENA*, S P DATTA, B S DWIVEDI, D GOLUI, ASHOK KUMAR, GANPAT LOUHAR and RAJKUMAR MEENA

ICAR-Indian Agricultural Research Institute, New Delhi 110 012, India

Received: 27 August 2020; Accepted: 21 September 2020

ABSTRACT

A field experiment was conducted to evaluate the long-term sewage sludge (SS) and fertilizer impact on yield and farm profitability in maize (*Zea mays* L.) grown at the ICAR-IARI, New Delhi during 2014–17. The experiment was laid out in a randomized complete block design with eight different treatment combinations comprising of different levels of sludge and fertilizer as follows: T1= control (no sludge and NPK fertilizer), T2= 100% recommended dose of NPK (NPK), T3= 25% N substituted by sludge +75% N + PK, T4= 50% N substituted by sludge + 50% N + PK, T5= 100% N substituted by sludge + PK, T6= Two times of sludge as applied in T5 + PK, T7= Three times of sludge as applied in T5 + PK and T8= NPK+2.5 t sludge/ha. Results revealed that the combined application of sludge @ 2.5 t/ha along with NPK (T8) showed highest grain yield of maize i.e. 5.93 t/ha. Total P, K and micronutrients uptake by straw and grain of maize were found to be highest in T7 treated plot. The maximum gross return, net return and B:C ratio were recorded under NPK along with 2.5 SS t/ha. Application of sludge not only enhanced the crop productivity of maize by supplying major and micronutrients, but also enriched maize grain with micronutrients like Zn and Fe throughout the treatments. Finally, it can be concluded that the treatment T8 i.e. NPK+2.5 SS t/ha could be an effective option for getting higher profitability and better quality yield of maize.

Key words: Micronutrient, Maize, Profitability, Primary nutrient, Sludge, Yield

In India, according to the CPCB (2016), total sewage produced from urban areas has been measured at 62,000 million liters per day (MLD), whereas Indian sewage treatment plants capacity is only 23,277 MLD, or 37% of the sewage generated. The generation of sludge is increasing day by day due to rapid urbanization and industrialization. The municipalities all over the world are concerned with safe and feasible method of its disposal. Therefore, the only viable option for sludge management is its utilization in agriculture as an alternate source of organic matter and plant nutrients. Sludge is a good source of plant nutrients and organic matter (Meena *et al*. 2008, Golui *et al*. 2014, Meena and Patel 2018, Verma *et al*. 2020). The nutrient content of sludge sustains soil fertility and organic constituents improve soil properties (Singh and Agrawal 2010, Meena *et al.* 2013). However, sludge may contain of toxic heavy metals, which may arise during sludge generation process while treating both industrial and domestic effluents (Dai *et al.* 2006). The Indo-Gangetic Plain of India, covering about 44 Mha, is the most important food-producing region of South Asia. It is dominated by cereals, of which irrigated maize-wheat system (MWS) are the third most important (1.13 Mha) system after rice-wheat and cotton-wheat systems (Jat *et al.* 2015). However, these systems are not sustainable due to the decline in soil fertility, especially in the level of organic matter. The factor productivity of fertilizers also decreased, asking for a higher amount of plant nutrients to obtain the same yield. In this scenario, sludge generated by sewage treatment plants may be used as an alternate source of nutrients and organic matter in sustaining crop productivity. Very few information is available on crop productivity, nutrient accumulation and economic profitability of maize grown in long-term sludge treated soil. With this background, the present study was undertaken with the objectives of i) assessing the effect of sludge and fertilizer application on yield of maize grown in sludge treated soil and ii) to study the impact of long-term sludge application on nutrient uptake and profitability of maize.

MATERIALS AND METHODS

Experimental site and treatments: A long-term field experiment was conducted during 2014–17 at ICAR-IARI. The experimental site was located at 28° 38’ N latitude, 77° 9' E longitude and 228 metres amsl. Climate

*Corresponding author e-mail: mcmeena@gmail.com

of the experimental site was semi-arid, subtropical with extreme temperature during hot and dry summers (May-June) and severe cold winters (December-January). The average minimum and maximum temperatures are 17.0 and 32°C, respectively. The mean yearly precipitation varied from 750–800 mm and over 85% precipitation occurred during monsoon (July-September). Initial properties of experimental soil had sand clay loam texture, Walkley-Black carbon (0.33%), *p*H (8.34) and electrical conductivity (0.33 dS/m). Available N, P and K content in soil were 171, 28.1 and 265 kg/ha, respectively. DTPA-extractable micronutrients (Zn, Cu, Fe and Mn) content in soil were 1.91, 2.33, 4.42 and 3.39 mg/kg, respectively. This soil was associated with Indo-Gangetic Plains having Mahrauli series of order Inceptisol and taxonomically classified as "Typic Haplustept". The experimental plots have dimensions of (5 m × 6 m) with eight treatments and three replications in a randomized block design. The treatments included, T1= control (no sludge and NPK fertilizer), T2= 100% recommended dose of NPK (NPK), T3= 25% N substituted by sludge + 75%N + PK, T4= 50% N substituted by sludge + 50%N + PK, T5= 100% N substituted by sludge (11.2 t/ha) + PK, T6= Two times of sludge as applied in T5 + PK, T7= Three times of sludge as applied in T5 + PK and T8= NPK+2.5 t sludge/ha.

Collection of sludge: Collection of sludge sample was undertaken from sewage treatment plant in Delhi, viz. Okhla during June, 2017. The sludge sample was dried in air, naturally crushed with mortar and pestle following sieving using a 2 mm sieve and subsequently processed and well blended sludge stored in polythene bags for further chemical analysis. This processed sludge was further used for field experiment.

Sowing of maize crop: Sowing of maize cultivar PMH-1 was carried out in the month of July (1st week) and harvested in the month of October (last week). Doses of N-P_2O_5-K_2O based on soil test for maize were 150-60-50 kg/ha, respectively. Urea, diammonium phosphate and murate of potash, was applied as a source of fertilizer N, P_2O_5 and K_2O, respectively. Single super phosphate has been used to supply P_2O_5 in T6 and T7 treated plots. Full recommended dose of phosphorus and potassium were applied uniformly to all plots as basal dressing whereas, nitrogen was applied to the plots according to the treatment in split (3 equal) doses. Three equal doses of nitrogen (1/3rd) were applied at the time of sowing (depth 2–3 cm), knee high stage (20–25 DAS) and tasselling of cob.

Plant sample collection and their analysis: Yield of maize grain and straw was recorded as per standard procedure during 2017. Maize cob and stover collected from each plot were cleaned with running tap water, then by using dilute acid and finally with distilled water. Plant samples were dried in hot-air oven at 60±2°C till constant weight before processing for analysis. Dry matter yield was recorded after achieving constant weight. For computation of uptake of nutrients in both grain and straw, nutrient content was multiplied with grain and straw yield, respectively.

The net return of maize grown under various treatments was calculated by subtracting cost of cultivation of individual treatment from gross returns of respective treatments, and finally the benefit:cost ratio was calculated. All the data recorded were subjected to one-way analysis of variance (ANOVA) using Statistical Analysis Software (SAS 9.4, SAS Institute Inc. 2016) software. Duncan's multiple range test (DMRT) was performed to test the significance of difference between the treatments.

RESULTS AND DISCUSSION

Chemical characteristic of sludge: The *p*H and electrical conductivity (EC) of experimental sludge were 5.67±0.03 and 3.63±0.04 dS/m, respectively. Total carbon (TC) content in sludge was 18.6±0.46%. Total N, P and K content in sludge were 1.35±0.05, 1.16±0.11 and 0.28±0.06%, respectively. Total S content in sludge was recorded as 0.92±0.03%. Total Zn, Cu, Mn, Ni, Cd and Pb content in sludge were 418±41.9, 105±6.11, 288±12, 19.3±1.33, 3.24±0.70 and 26.7±1.98 mg/kg, respectively, whereas content of Fe was 1.53±0.02%. According to Council of the European Communities (1986), the permissible levels for potential toxic elements such as Zn, Cu, Cd, Pb and Ni in sludge to be used in agricultural soils are 2500, 1000, 20, 750 and 300 mg/kg, respectively. Therefore, content of potential toxic element in sludge as used in the present study was within the permissible limit as prescribed by the Council of the European Communities.

Effect of sludge and fertilizer application on yield and farm profitability of maize crop: The yield of maize crop was significantly higher in all treatments compared to control (Table 1). Highest grain and straw yield was recorded in NPK+2.5 t SS/ha, which was significantly higher than rest of the treatments. Lowest grain and straw yield was recorded in control (T1) i.e. 2.07 and 7.70 t/ha, respectively. There was no significant difference in yield of both grain and straw within the treatments from T2–T7. Sludge is a good source of organic matter and plant nutrients. Application of sludge to soil provides energy to soil microbes and helps in improving microbial activities and soil physical environment (Meena and Patel 2018). As a results of these properties, the availability of nutrients in soil enhanced which helps in growth and development of plants. These findings indicated the significance of sludge application to enhance the grain and straw yield of maize than fertilizer application alone (Meena *et al.* 2008, Zoubi *et al.* 2008, Motta and Maggiore, 2013, Delibacak and Ongun 2016).

The highest cost of cultivation of maize was recorded with T7 (three times of sludge as applied in T5 + PK) (₹65980/ha) and T6 (two times of sludge as applied in T5 + PK) (₹54780/ha) over other treatments. Similarly, the highest cost of treatment (₹37982/ha) was recorded T7 (three times of sludge as applied in T5 + PK). The maximum gross return (₹102756/ha), net return (₹66360/ha) and B:C ratio (1.82) was reported with T8 (100% recommended dose of NPK+2.5 SS t/ha). In case of T3 (25% N substituted by sludge + 75% N + PK), gross return (₹88467/ha) and net return (₹52220/ha) proved to be second best option for

Table 1 Effect of sludge and fertilizer application on yield (t/ha) and farm profitability of maize

Treatment	Yield (t/ha)			Profitability				
	Grain	Straw	Biological	Cost of cultivation (₹/ha)	Cost of treatments (₹/ha)	Gross return (₹/ha)	Net return (₹/ha)	B:C Ratio
T1	2.07^{d}	5.63^{c}	7.70^{e}	27998	0.00	38000	10002	0.36
T2	5.04^{bc}	9.47^{b}	14.5^{bc}	33896	5898	85978	52082	1.54
T3	5.18^{b}	9.79^{b}	15.0^{b}	36247	8249	88467	52220	1.44
T4	4.59^{bc}	9.19^{b}	13.8^{bcd}	38598	10600	79201	40603	1.05
T5	4.44^{c}	8.38^{b}	12.8^{cd}	43580	15582	75890	32310	0.74
T6	4.30^{c}	8.15^{b}	12.5^{d}	54780	26782	73518	18738	0.34
T7	4.74^{bc}	9.86^{b}	14.6^{bc}	65980	37982	82381	16401	0.25
T8	5.93^{a}	12.2^{a}	18.1^{a}	36396	8398	102756	66360	1.82
LSD (P=0.05)	0.74	1.95	1.89	--	--	--	--	--

Values followed by common letters in column are not significantly different (LSD, $P \leq 0.05$)

T1, control (no sludge and NPK fertilizer); T2, 100% recommended dose of NPK; T3, (25% N substituted by sludge + 75% N+ PK); T4, (50% N substituted by sludge + 50% N+PK); T5, (100% N substituted by sludge + PK); T6, (Two times of sludge as applied in T5 + PK); T7, (Three times of sludge as applied in T5 + PK) and T8, (100% recommended dose of NPK+2.5 t sludge/ha).

farmers after T8, i.e.100% recommended dose of NPK+2.5 SS t/ha. The application of T8 (100% recommended dose of NPK+2.5 SS t/ha) enhanced the gross return with magnitude of 170 and 20%, net return by 563 and 27% and B:C ratio by 405 and 18% over control and 100% recommended dose of NPK treatment, respectively (Table 1). The combined use of inorganic fertilizers and organic sludge may be improving physical, chemical and biological properties of soil which in turn improves its nutrient supplying capacity (Hao and Chang 2002) and enhance higher nutrient uptake and yield by maize crop. Combined application of inorganic fertilizer along with sludge led to supplying more available nutrients followed by increased yield might be the principal reason for higher gross return, net return and B:C ratio under T8 (100% recommended dose of NPK+2.5 SS t/ha) treatment. Similar findings of increased crop yield and profitability with combined application inorganic fertilizer along with organic source has been reported by Yadav *et al.* (2019).

Effect of sludge and fertilizer application *on uptake of primary nutrients in maize crop*: The N, P and K uptake in maize (grain plus straw) varied from 35.3–149, 15.0–52.7 and 43.2–119 kg/ha, respectively (Table 2). The N uptake under NPK+2.5 t SS/ha was found to be significantly higher than other treatments. The T6 (two times of sludge as applied in T5 + PK) treated plot along with T2 (100% recommended dose of NPK), T3 (25% N substituted by sludge + 75%N + PK), T4 (50% N substituted by sludge + 50% N + PK) and T5 (100% N substituted by sludge + PK) also showed significantly higher amount of N uptake by maize (grain plus straw) compared to that in control. The uptake of P in maize (grain plus straw) was significantly higher in T7 (three times of sludge as applied in T5 + PK) compared to other seven treatments. Addition of sludge was also highest in T7 i.e. 33 t/ha. In case of K, significantly higher uptake was recorded in T7 and T8 compared to other six treatment combination. Uptake of K by grain and straw of maize was found to statistically at par for treatment T2–T6. Sludge contains higher amount of major plant nutrients, which provides balanced plant nutrition to enhance the total biomass as well as nutrient contents of the crop. Uptakes of N, P and K by straw and grain of maize was increased with the increasing levels of sludge application. The sludge used for present investigation had 1.35% N, 1.16% P and 0.28% K. In addition, apart from the enhanced nutrient supply, the positive influence of the sludge application on the growth of plants and N, P and K uptake could be due to the improving soil properties (Meena *et al.* 2013, Khanmohammadi *et al.* 2017).

Effect of sludge and fertilizer application on uptake of micronutrients in maize crop: The Zn, Cu, Fe and Mn uptake in maize ranged from 354–1181, 29.6–93.4, 1039–3767 and 133–440 g/ha, respectively (Table 2). Significantly higher uptake of all micronutrients was observed under T7 (three times of sludge as applied in T5 + PK) followed by T8 (100% recommended dose of NPK+2.5 SS t/ha and T6 (two times of sludge as applied in T5 + PK) over control except Mn. The uptake of Mn by maize was significantly highest under 100% recommended dose of NPK+2.5 SS t/ha, which was 231% higher than control. This might be attributed to the high content of micronutrients in sludge as chelated complex, and their release in soils to fulfil the requirement of the plants as per their needs. Thus, DTPA-extractable micronutrients contents in soil were increased under sludge amended soil, which could be a reason for enhancing the uptake of these elements by maize crop (Meena *et al.* 2008, Zoubi *et al.* 2008, Latare *et al.* 2014, Yang *et al.* 2018).

The present investigation highlights the importance of incorporation of sludge along with NPK for getting high production without undermining the quality of produce. Application of sludge not only enhanced the crop productivity of maize by supplying major and micronutrients, but also

Table 2 Effect of sludge and fertilizer application on primary nutrients (kg/ha) and micronutrients uptake (g/ha) by maize crop

Treatment	Nitrogen			Phosphorus			Potassium			Zinc			Copper			Iron			Manganese		
	Grain	Straw	Total	Grain	Straw	Total	Grain	Straw	Total	Grain	Straw	Total	Grain	Straw	Total	Grain	Straw	Total	Grain	Straw	Total
T1	18.7^{c}	16.6^{d}	35.3^{d}	6.39^{c}	8.61^{f}	15.0^{d}	5.16^{c}	38.0^{c}	43.2^{c}	52.5^{d}	301^{d}	354^{e}	7.79^{c}	21.9^{d}	29.6^{d}	73.7^{d}	965^{d}	1039^{d}	6.11^{e}	127^{c}	133^{c}
T2	49.2^{b}	33.7^{c}	82.9^{c}	19.3^{ab}	11.8^{ef}	31.1^{c}	13.7^{b}	64.9^{b}	78.6^{b}	129^{bc}	543^{c}	672^{d}	20.9^{b}	39.9^{c}	60.8^{c}	197^{c}	1778^{c}	1975^{c}	21.8^{d}	268^{b}	290^{b}
T3	56.7^{b}	31.6^{c}	88.3^{c}	20.3^{ab}	16.6^{cd}	36.9^{bc}	15.0^{ab}	72.8^{b}	87.8^{b}	140^{ab}	625^{bc}	765^{bcd}	26.0^{ab}	43.9^{bc}	69.9^{c}	259^{b}	2127^{bc}	2386^{bc}	29.1^{b}	320^{ab}	349^{ab}
T4	46.9^{b}	33.1^{c}	80.0^{c}	17.8^{b}	19.3^{bc}	37.1^{bc}	13.3^{b}	72.9^{b}	86.2^{b}	113^{c}	619^{bc}	732^{cd}	25.8^{ab}	41.5^{c}	67.3^{c}	245^{b}	2050^{bc}	2295^{bc}	22.9^{cd}	309^{ab}	332^{ab}
T5	47.9^{b}	31.2^{c}	79.1^{c}	18.5^{ab}	19.1^{bc}	37.6^{b}	13.3^{b}	68.2^{b}	81.5^{b}	124^{bc}	737^{b}	861^{bc}	26.9^{a}	42.0^{bc}	68.9^{c}	247^{b}	1978^{bc}	2225^{bc}	26.5^{bcd}	318^{ab}	345^{ab}
T6	56.0^{b}	30.4^{c}	86.4^{c}	18.0^{ab}	22.1^{b}	40.1^{b}	13.9^{ab}	66.6^{b}	80.0^{b}	126^{bc}	751^{b}	877^{bc}	28.0^{a}	42.9^{bc}	70.9^{bc}	273^{b}	2035^{bc}	2308^{bc}	28.6^{bc}	316^{ab}	345^{ab}
T7	62.8^{b}	43.1^{b}	106^{b}	21.1^{ab}	31.6^{a}	52.7^{a}	15.5^{ab}	103^{a}	119^{a}	157^{a}	1024^{a}	1181^{a}	26.1^{ab}	67.3^{a}	93.4^{a}	328^{a}	3439^{a}	3767^{a}	36.1^{a}	391^{a}	427^{a}
T8	86.7^{a}	62.4^{a}	149^{a}	22.1^{a}	14.4^{de}	36.5^{bc}	16.7^{a}	92.7^{a}	109^{a}	156^{a}	778^{b}	934^{b}	28.7^{a}	53.4^{b}	82.1^{ab}	271^{b}	2667^{b}	2938^{b}	29.5^{b}	411^{a}	440^{a}
LSD (P=0.05)	19.1	6.20	15.3	4.78	4.33	6.35	2.98	17.7	17.9	23.1	175	174	5.42	11.5	11.8	46.3	738	733	5.85	118	120

Values followed by common letters in column are not significantly different (LSD, $P\leq0.05$)

T1, control (no sludge and NPK fertilizer); T2, 100% recommended dose of NPK; T3, (25% N substituted by sludge + 75%N+ PK); T4, (50% N substituted by sludge + 50%N+PK); T5, (100% N substituted by sludge + PK); T6, (Two times of sludge as applied in T5 + PK); T7, (Three times of sludge as applied in T5 + PK) and T8, (100% recommended dose of NPK+2.5 t sludge/ha).

enriched maize grain with micronutrients like Zn and Fe throughout the treatments. Finally, it can be concluded that the treatment T8 i.e. 100% recommended dose of NPK+2.5 SS t/ha could be an effective option for getting higher profitability and better quality yield of maize.

ACKNOWLEDGEMENTS

The authors sincerely acknowledge the support received from the Division of Soil Science and Agricultural Chemistry, ICAR-IARI New Delhi for conducting this research work and also acknowledge ICAR-AICRP-MSPE, Anand Centre, Gujarat for providing ICP-OES facility for sample analysis.

REFERENCES

Council of the European Communities. 1986. Council Directive of 12 June 1986 on the Protection of Environment and in Particular of the Soil, when Sewage Sludge is used in Agriculture (86/278/EEC). Off. J. Eur. Comm., No. L 181/6-12.

CPCB. 2016. Performance evaluation of sewage treatment plants under NRCD. Central Pollution Control Board, Delhi, India.

Dai J Y, Ling C H E N, Zhao J F and Na M A. 2006. Characteristics of sewage sludge and distribution of heavy metal in plants with amendment of sewage sludge. *Journal of Environmental Sciences* **18**(6): 1094–1100.

Delibacak S and Ongun A R. 2016. Influence of treated sewage sludge applications on corn and second crop wheat yield and some properties of sandy clay soil. *Turkish Journal of Field Crops* **21**: 1–9.

Golui D, Datta S P, Rattan R K, Dwivedi B S and Meena M C. 2014. Predicting bioavailability of metals from sludge-amended soils. *Environmental Monitoring and Assessment* **186**(12): 8541–53.

Hao X and Chang C. 2002. Effect of 25 annual cattle manure applications on soluble and exchangeable cations in soil. *Soil Science* **167**(2): 126–34.

Jat H S, Singh G, Singh R, Choudhary M, Jat M L, Gathala M K and Sharma D K. 2015. Management influence on maize-wheat system performance, water productivity and soil biology. *Soil Use and Management* **31**(4): 534–43.

Khanmohammadi Z, Afyuni M and Mosaddeghi M R. 2017. Effect of sewage sludge and its biochar on chemical properties of two calcareous soils and maize shoot yield. *Archives of Agronomy and Soil Science* **63**(2): 198–212.

Latare A M, Kumar O, Singh S K and Gupta A. 2014. Direct and residual effect of sewage sludge on yield, heavy metals content and soil fertility under rice-wheat system. *Ecological Engineering* **69:** 17–24.

Meena M C and Patel K P. 2018. Effect of long-term application of sewage sludge and farmyard manure on soil properties under mustard-based cropping system. *Journal of Oilseed Brassica* **9**(2): 96–103

Meena M C, Patel K P and Ramani V P. 2013. Effect of FYM and sewage sludge application on yield and quality of pearl millet-mustard cropping system and soil fertility in a Typic Haplustept. *Journal of the Indian Society of Soil Science* **61**(1): 55–58.

Meena M C, Patel K P, Dhyan-Singh and Dwivedi B S. 2008. Long-term effect of sewage sludge and farmyard manure on grain yields and availability of zinc and iron under pearlmillet (*Pennisetum glaucum*)-India mustard (*Brassica juncea*) cropping sequence. *Indian Journal of Agricultural Sciences,*

78(12): 1028–32.

Motta S R and Maggiore T. 2013. Evaluation of nitrogen management in maize cultivation grows on soil amended with sewage sludge and urea. *European Journal of Agronomy* **45**: 59–67.

Singh R P and Agrawal M. 2010. Variations in heavy metal accumulation, growth and yield of rice plants grown at different sewage sludge amendment rates. *Ecotoxicology and Environmental Safety* **73**(4): 632–41.

Verma A K, Singh R D, Datta S P, Kumar S, Mishra R, Trivedi V K, Sharma V K and Meena M C. 2020. Risk assessment through rice in sludge treated soil. *Indian Journal of Agricultural Sciences* **90**(7): 1310–14.

Yadav M R, Kumar Y, Pooniya V, Gupta K C, Saxena R, Garg N K and Singh A. 2019. Performance of groundnut (*Arachis hypogaea* L.) under different phosphorus management options in semi-arid environment of Rajasthan. *Indian Journal of Agricultural Sciences* **89**(6): 946–50.

Yang G H, Zhu G Y, Li H L, Han X M and Li J M. 2018. Accumulation and bioavailability of heavy metals in a soil-wheat/maize system with long-term sewage sludge amendments. *Journal of Integrative Agriculture* **17**(8): 1861–70.

Zoubi M M A, Arslan A, Abdelgawad G, Pejon N, Tabbaa M and Jouzdan O. 2008. The effect of sewage sludge on productivity of a crop rotation of wheat, maize and vetch and heavy metals accumulation in soil and plant in Aleppo Governorate. *American-Eurasian Journal of Agricultural and Environmental Sciences* **3**(4): 618–25.