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Effect of Long-term Integration of Sewage-Sludge and Fertilizers on Wheat Productivity, Profitability and Soil Fertility

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A field experiment was carried out to assess the effect of long-term combined application of sewage sludge (SS) and chemical fertilizers on yield, nutrient uptake, soil fertility status and economics of wheat (*Triticum aestivum* L.) grown in the experimental plot of ICAR-Indian Agricultural Research Institute (IARI), New Delhi, India. The experiment comprised of eight different treatment combinations including different levels of sludge and fertilizers. The sludge treatments were applied before sowing of *kharif* maize (*Zea mays* cv. PMH-1) in maize-wheat cropping system, while *rabi* wheat (*Triticum aestivum* cv. HD-3059) was grown with recommended dose of NPK. Results revealed that pH, electrical conductivity (EC) and available potassium (K) content in soil were not significantly affected by the application of sludge. However, soil organic carbon (SOC), cation exchange capacity (CEC), available nitrogen (N) and phosphorus (P) content in soil were significantly increased over control due to application of sewage-sludge. The combined application of sludge @ 2.5 t ha^{-1} along with NPK showed the highest grain yield, agronomic efficiency and total N, P and K uptake by wheat crop. The maximum gross return, net return and B:C ratio were recorded under combined application of NPK and SS @ 2.5 t ha^{-1}. The present study showed that integrated use of 100% NPK along and SS @ 2.5 t ha^{-1} could be an effective option for enhancing wheat yield, soil fertility status, and economic return.

Key words: Sewage sludge application, soil fertility, yield, agronomic use efficiency, nutrient uptake, profitability

Sewage sludge (SS) generation is being escalated day by day because of the ever increasing population and rapid urbanization. The total output of sewage generated in the country from urban areas is around 72368 million litres per day (MLD), out of which only about 51% treated. In Delhi, a total of 38 sewage treatment plants (STPs) have been operational with total treatment capacity of 2896 MLD (CPCB 2021). Appropriate disposal of this huge quantity of sewage sludge is a major challenge in India as well as in the world. Use of sludge in agriculture as organic manures and a source of plant nutrients seems to be a lucrative option. Land application of SS in agriculture is associated with recycling of organic matter, nitrogen (N), phosphorus (P), potassium (K) and other plant nutrients (Meena *et al.* 2008; Golui *et al.* 2014; Meena and Patel 2018; Verma *et al.* 2020, 2021) and capable of substituting the expensive fertilizers in croplands as well (Liu and Sun 2013). Besides, important soil properties were reported to improve with the application of sludge (Singh and Agrawal 2010; Meena *et al.* 2013). However, sludge may contain high amount of toxic heavy metals such as lead (Pb), cadmium (Cd), nickel (Ni), chromium (Cr) and mercury (Hg) (Dai *et al*. 2006). Hence, the application of SS may contribute to the build-up of toxic trace metals in soil, which subsequently transfer to food chain. The extent of food chain contamination depends on the nature and composition of the SS, its application rate, soil properties, crop species and management practices.

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Wheat (*Triticum aestivum* L.)is the most important source of protein and food calories at the global level, and is part of many food products, such as bread, pasta, pastries, noodles, semolina, bulgur or couscous. It is also the food crop that covers the largest share of the global crop area (about 14%) and has the largest share in global food trade (OECD-FAO Agricultural Outlook 2020). In 2019, wheat was grown over 214 million hectare (Mha) area producing around 762.2 metric tonnes in world (Index Box AI Platform 2020). India is the second largest producer of wheat in the world. According to ICAR-IIWBR (2018-19), total production of wheat in India was 101.20 million tonnes (Mt) from an area of 29.55 Mha with a productivity of 3.44 t ha^{-1}. Scarce information is available on crop productivity, soil fertility, nutrient accumulation and economic profitability of wheat 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 soil fertility status and yield of wheat crop and ii) to study the impact of long-term sludge application in soil on nutrient uptake and profitability of wheat.

Materials and Methods

Experimental site and treatment detail

A long-term experiment on "Impact of sludge application on soil health and metal uptake by plant under maize (*Zea mays* L.) - wheat (*Triticum aestivum* L.) cropping system" was initiated in 2014-15 at Mid-Block 8B of ICAR-IARI. The experimental site was located at 28°38′ N latitude, 77°9′ E longitude and 228 m above mean sea level. The climate of the experimental site was semi-arid, sub-tropical with extreme temperature during hot and dry summer (May-June) and severe cold winter (December-January). The average minimum and maximum temperatures are 17.0 and 32 °C, respectively. The mean yearly precipitation varied from 750 to 800 mm and over 85% of precipitation occurred during the monsoon period (July-September). The soil samples were analyzed for pH, EC (Jackson 1973), organic carbon (Walkley and Black 1934), available N by alkaline permagnate (Subbiah and Asija 1956), available P by $NaHCO_3$-extractable P (Olsen *et al.* 1954), and available K by ammonium acetate (Jackson 1973). The experiments with eight treatments and three replications were laid in randomized block design having a plot size of 5 × 6 m^2. The treatments include control (no SS and NPK fertilizer), 100% recommended dose of NPK (NPK), $N_{25\%}$ (SS) + $N_{75\%}$ + PK, $N_{50\%}$ (SS) + $N_{50\%}$ + PK, $N_{100\%}$ (SS) + PK, $N_{200\%}$ (SS) + PK, $N_{300\%}$ (SS) + PK and NPK + 2.5 t SS/ha. Initial properties of experimental soil had sandy clay loam texture, low in Walkley-Black carbon (0.33%), alkaline pH (8.34) and electrical conductivity (EC 0.33 dS m^{-1}). Available N, P and K content in soil were 171, 28.1 and 265 kg ha^{-1}, respectively.

Collection of sludge

The sludge sample was collected from Okhla sewage treatment plant (STPs) in Delhi during June, 2017. The sludge sample was dried in air naturally, crushed with pestle and mortar followed by sieving with a 2-mm sieve (Verma *et al.* 2020). Processed sludge was further used for field experiment. The sludge was applied as per treatments before sowing of *kharif* maize (cv. PMH-1) in maize-wheat cropping system, while *rabi* wheat (cv. HD-3059) was grown with recommended dose of NPK.

Sowing of wheat crop

After harvest of maize crop, wheat (HD-3059) was sown in the month of mid-November and harvested in the month of April, 2018. Recommended dose of fertilizer (RDF) based on soil test values for wheat was $N:P_2O_5:K_2O$:: 150:60:50 kg ha^{-1}. Urea, diammonium phosphate (DAP) and murate of potash (MOP) were applied as source of N, P_2O_5 and K_2O, respectively. Full recommended dose of P and K were applied uniformly to all plots as basal whereas, N was applied according to the treatments in split (3 equal) doses. Three equal doses of N ($1/3^{rd}$) were applied at the time of sowing, first irrigation (CRI stage 20-25 DAS) and after the second irrigation of wheat.

Soil and plant samples collection and their analysis

Soil and plant samples were collected after harvest of wheat crop in the year 2018. The grain and straw yields were recorded as per standard procedure. Grain and straw samples of wheat from each plot were cleaned with running tap water, dilute HCl acid and finally with distilled water. Plant samples were dried in hot-air oven at 60±2 °C till the attainment of constant weight before processing for analysis. For the computation of uptake of nutrients in both grain and straw, nutrient content was multiplied with grain and straw yield, respectively.

Agronomic efficiency

Agronomic efficiency of fertilizer is defined as the increase in wheat grain yield per unit of fertilizer applied:

$$AEF = \frac{Yf - Yc}{F\ appl}$$

where, Y_f and Y_c refer to grain yields (kg ha^{-1}) in the treatment where fertilizer was applied and in the control plot, respectively, and F appl. is the amount of fertilizer applied (kg ha^{-1}). Contribution of N, P and K from sludge in computing agronomic use efficiency of fertilizer N, P and K was not taken account.

The net return of wheat 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 (Gomez and Gomez 1984).

Results and Discussion

Chemical characteristic of sludge

The pH and EC of experimental sludge were 5.67±0.03 and 3.63±0.04 dS m^{-1}, 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^{-1}, 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^{-1}, 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 of wheat crop

The yield of wheat crop was significantly higher in all treatments compared to control (Table 1). The highest grain, straw and biological yield was recorded in NPK+2.5 t SS ha^{-1}, which was significantly higher than rest of the treatments. The lowest grain, straw and biological yield was recorded in control *i.e.* 2.82, 4.70 and 7.52 t ha^{-1}, respectively. There was no significant difference in yield of grain, straw and biological within the treatments from NPK to $N_{300\%}$ (SS) + PK. Sludge is a good source of organic matter and plant nutrients. The application of sludge to soil provides energy to soil microbes and helps in improving microbial activities and soil physical environment (Meena and Patel 2018). Thus, availability of nutrients in soil enhanced due to sludge application, which helps in growth and development of plants. These findings indicated the significance of sludge application to enhance the grain and straw yield of wheat than fertilizer application alone (Meena *et al.* 2008; Motta and Maggiore 2013; Delibacak and Ongun 2016).

Effect of sludge application on agronomic efficiency (AE) of fertilizer in wheat crop

Agronomic efficiency of fertilizer (N, P and K)

Table 1. Effect of sewage sludge and fertilizer application on wheat yield, harvest index and agronomic use efficiency

Treatments	Yield (t ha^{-1})			HI	Agronomic use efficiency (kg grain kg^{-1})		
	Grain	Straw	Biological	(%)	Nitrogen	Phosphorus	Potassium
Control	2.82^{c}	4.70^{d}	7.52^{d}	37.8	-	-	-
NPK	4.96^{b}	7.58^{bc}	12.5^{bc}	39.6	14.3^{b}	35.7^{b}	42.9^{b}
$N_{25\%}$(SS) + $N_{75\%}$ + PK	5.05^{b}	8.03^{bc}	13.1^{b}	38.6	14.9^{b}	37.2^{b}	44.6^{b}
$N_{50\%}$(SS) + $N_{50\%}$ + PK	5.03^{b}	7.73^{bc}	12.8^{b}	39.4	14.8^{b}	36.9^{b}	44.3^{b}
$N_{100\%}$ (SS) + PK	4.60^{b}	6.82^{c}	11.4^{c}	40.4	11.9^{b}	29.8^{b}	35.7^{b}
$N_{200\%}$ (SS) + PK	4.67^{b}	7.27^{bc}	11.9^{bc}	39.1	12.3^{b}	30.8^{b}	37.0^{b}
$N_{300\%}$ (SS) + PK	4.65^{b}	8.45^{b}	13.1^{b}	35.7	12.2^{b}	30.6^{b}	36.7^{b}
NPK + 2.5 t SS ha^{-1}	5.92^{a}	9.86^{a}	15.8^{a}	37.5	20.7^{a}	51.7^{a}	62.0^{a}
LSD (P=0.05)	0.83	1.29	1.27	NS	4.77	11.9	14.3

Values followed by common letters in column are not significantly different (*P≤0.05*)

Table 2. Effect of long term sewage-sludge and fertilizer application on farm profitability of wheat cultivation

Treatments	Cost of cultivation (₹×10^3 ha^{-1})	Cost of treatments (₹×10^3 ha^{-1})	Gross return (₹×10^3 ha^{-1})	Net return (₹×10^3 ha^{-1})	B:C ratio
Control	26.7	0.00	56.8	30.1	1.13
NPK	32.6	5.89	98.9	66.3	2.03
$N_{25\%}$(SS) + $N_{75\%}$ + PK	32.6	5.89	101	68.6	2.10
$N_{50\%}$(SS) + $N_{50\%}$ + PK	32.6	5.89	100	67.8	2.08
$N_{100\%}$ (SS) + PK	32.6	5.89	91.4	58.8	1.80
$N_{200\%}$ (SS) + PK	32.6	5.89	93.3	60.7	1.86
$N_{300\%}$ (SS) + PK	32.6	5.89	95.0	62.4	1.91
NPK + 2.5 t SS ha^{-1}	32.6	5.89	119	86.8	2.66

varied from 11.9 to 20.7, 29.8 to 51.7 and 35.7 to 62.0 kg kg^{-1}, respectively among the treatments (Table 1). Significantly highest efficiency of fertilizers was recorded under NPK+2.5 t SS ha^{-1} treatment whereas, rest of the treatments were more or less similar. It might be due to combined application of sludge along with fertilizer released more nutrient as compared to alone applied organic source and mineral fertilizer. Swain *et al*. (2020) also reported that nutrient use efficiency increased recommended dose of NPK as compared to sludge application.

Effect of sludge and fertilizer application on farm profitability

The maximum gross return (₹ 119×10^3 ha^{-1}), net return (₹ 86.8 ×10^3 ha^{-1}) and B:C ratio (2.66) was reported with NPK+2.5 SS t ha^{-1}. In case of $N_{25\%}$(SS) + $N_{75\%}$ + PK treatment gross return (₹ 101×10^3 ha^{-1}) and net return (₹ 68.6 ×10^3 ha^{-1}) and B:C ratio (2.10) proved to be second best option for farmers after NPK+2.5 SS t ha^{-1} (Table 2). The application of NPK+2.5 SS t ha^{-1} enhanced the gross return with magnitude of 21 per cent, net return by 31 per cent and B:C ratio by 31 per cent over 100% recommended dose of NPK treatment, respectively. The integrated use of chemical fertilizers along with organic sludge is capable of improving physicochemical and biological properties of soil, thereby improving the nutrients supplying ability of soil (Hao and Chang 2002) and increase higher nutrient uptake and yield by wheat crop. Similar findings of increased the crop yield and profitability with combined application inorganic fertilizer along with organic source has been reported by Yadav *et al.* (2019) and Verma *et al.* (2021).

Effect of sludge and fertilizer application on uptake of nutrients in wheat crop

The data pertaining to nutrient (N, P and K) uptake by wheat crop are presented in table 3. Nitrogen uptake by wheat was in the range of 46.7 to 170 kg ha^{-1}, while the corresponding figures for P and K were 7.93 to 25.6 and 54.6 to 136 kg ha^{-1}, respectively. The N uptake under NPK+2.5 t SS ha^{-1} was found to be significantly higher than other treatments. The treatment $N_{200\%}$ (SS) + PK, $N_{25\%}$ (SS) + $N_{75\%}$ + PK, $N_{50\%}$ (SS) + $N_{50\%}$ + PK and $N_{100\%}$ (SS) + PK were also associated with significantly higher N uptake by wheat (grain plus straw) compared to that in control. The total uptake of P by wheat (grain plus

Table 3. Effect of sewage sludge application on nutrients uptake (kg ha^{-1}) by wheat

Treatments	Nitrogen			Phosphorus			Potassium		
	Grain	Straw	Total	Grain	Straw	Total	Grain	Straw	Total
Control	34.0^{c}	12.7^{d}	46.7^{d}	7.05^{c}	0.88^{d}	7.93^{d}	8.08^{c}	46.5^{d}	54.6^{d}
NPK	90.1^{b}	38.7^{bc}	129^{bc}	17.6^{b}	1.48^{d}	19.1^{c}	14.0^{b}	90.7^{c}	105^{c}
$N_{25\%}$(SS) + $N_{75\%}$ + PK	89.6^{b}	40.5^{b}	130^{b}	18.7^{b}	2.27^{c}	21.0^{bc}	14.8^{b}	98.0^{bc}	113^{bc}
$N_{50\%}$(SS) + $N_{50\%}$ + PK	83.0^{b}	38.1^{bc}	121^{bc}	19.5^{ab}	2.39^{c}	21.9^{abc}	14.4^{b}	95.2^{bc}	110^{bc}
$N_{100\%}$ (SS) + PK	73.5^{b}	33.2^{c}	107^{c}	19.2^{ab}	2.51^{bc}	21.7^{abc}	13.3^{b}	89.1^{c}	102^{c}
$N_{200\%}$ (SS) + PK	78.5^{b}	39.2^{bc}	118^{bc}	19.2^{ab}	3.10^{b}	22.3^{abc}	14.2^{b}	97.4^{bc}	112^{bc}
$N_{300\%}$ (SS) + PK	76.9^{b}	44.4^{b}	121^{bc}	19.6^{ab}	4.38^{a}	24.0^{ab}	14.7^{b}	113^{ab}	128^{ab}
NPK + 2.5 t SS ha^{-1}	114^{a}	55.8^{a}	170^{a}	23.1^{a}	2.48^{bc}	25.6^{a}	18.3^{a}	118^{a}	136^{a}
LSD (P=0.05)	21.8	7.23	22.3	4.21	0.63	4.14	3.27	18.5	19.8

Values followed by common letters in column are not significantly different (*LSD=P≤0.05*)

Table 4. Effect of sewage sludge application on chemical properties and available nutrients in soil

Treatments	Chemical properties				Available nutrients (kg ha^{-1})		
	$pH_{1:2}$	$EC_{1:2}$ (dS m^{-1})	SOC (%)	CEC [cmol(p^{+})kg^{-1}]	Nitrogen	Phosphorus	Potassium
Control	8.65	0.182	0.30^{d}	13.3^{d}	154^{c}	26.8^{c}	253
NPK	8.57	0.178	0.37^{cd}	14.8^{bcd}	191^{ab}	30.9^{bc}	264
$N_{25\%}$(SS) + $N_{75\%}$ + PK	8.55	0.178	0.38^{cd}	15.6^{abcd}	192^{ab}	32.0^{bc}	275
$N_{50\%}$(SS) + $N_{50\%}$ + PK	8.54	0.194	0.44^{bc}	15.9^{abc}	186^{ab}	33.3^{ab}	275
$N_{100\%}$ (SS) + PK	8.54	0.195	0.44^{bc}	16.2^{abc}	188^{ab}	34.0^{ab}	299
$N_{200\%}$ (SS) + PK	8.53	0.182	0.50^{b}	16.6^{ab}	201^{ab}	36.5^{ab}	228
$N_{300\%}$ (SS) + PK	8.43	0.205	0.61^{a}	17.4^{a}	212^{a}	38.6^{a}	244
NPK + 2.5 t SS /ha	8.50	0.186	0.51^{b}	15.8^{abc}	198^{ab}	35.6^{ab}	266
LSD (P=0.05)	NS	NS	0.09	2.40	30.9	5.66	NS

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

straw) crop was significantly higher in NPK+2.5 t SS ha^{-1} compared control treatments but at par to other sludge treatments. In case of K, significantly higher uptake was recorded in all the treatment as compared to the control. The treatment $N_{300\%}$ (SS) + PK at par with $N_{200\%}$ (SS) + PK, $N_{25\%}$(SS) + $N_{75\%}$ + PK and $N_{50\%}$(SS) + $N_{50\%}$ + PK treatments. With increasing levels of sludge application, the total uptake of N, P and K by wheat was increased. There was 1.35% N, 1.16% P and 0.28% K in the sludge used for the current investigation. Furthermore, apart from the increased availability of nutrients, the beneficial impact of the application of sludge on plant growth and the uptake of N, P and K may be attributed to improved soil properties (Meena *et al.* 2013; Khanmohammadi *et al.* 2017).

Effect of sludge application on chemical properties and available nutrients in soil

The effect of continuous addition of SS over a time period of five years could not change soil pH, EC and K significantly, whereas, soil OC content, CEC, available N and P showed significant changes improvement in SS amended soils (Table 4). The value ranged from 0.30 to 0.61% for soil OC, 13.3 to 17.4 [cmol(p^{+}) kg^{-1}] for CEC, 154 to 212 kg ha^{-1} for available N and 26.8 to 38.6 kg ha^{-1} for available P. The treatment $N_{300\%}$ (SS) + PK showed 103, 31, 37.6 and 44 per cent higher values for soil OC, CEC, N and P, respectively than control. The possible reason behind the increase OC, CEC and available N and P content in soil may be related to fact that SS is a rich source of total C and nutrients. Available N, P and K content in soil was reported to increase earlier due to sludge application in several experiment (Meena *et al.* 2013; Rathod *et al.* 2013; Zuo *et al.* 2019).

Conclusions

The current study demonstrates the benefits of incorporation of sludge along with NPK for achieving higher productivity and profitability. Application of sludge not only improved the soil properties and nutrient supplying capacity but also enhanced crop productivity. Finally, it can be concluded that the treatment 100% recommended dose of NPK+2.5 SS t ha^{-1} could be an effective option for improving soil fertility and crop productivity.

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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 (2021) *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**, 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**, 8541-8553.

Gomez, K.A. and Gomez, A.A. (1984) *Statistical Procedures for Agricultural Research*. John Wiley and Sons.

Hao, X. and Chang, C. (2002) Effect of 25 annual cattle manure applications on soluble and exchangeable cations in soil. *Soil Science* **167**, 126-134.

ICAR-Indian Institute of Wheat and Barley Research, (2018-19) https://iiwbr.icar.gov.in/annual-report/.

Index Box AI Platform (2020) https://www.google.com/search?q=Index+Box+AI+Platform+2020&oq=Index+Box+AI+Platform+2020&aqs=chrome..69i57.1118j0j7&sourceid=chrome&ie=UTF-8.

Jackson, M.L. (1973) *Soil Chemical Analysis*. Prentic Hall India (Pvt.) Ltd. New Delhi.

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**, 198-212.

Liu, J.Y. and Sun, S.Y. (2013) Total concentrations and different fractions of heavy metals in sewage sludge from Guangzhou, China. *Transactions of Nonferrous Metals Society of China* **23**, 2397-2407.

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**, 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**, 55-58.

Meena, M.C., Patel, K.P., Singh, D. 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*)-Indian mustard (*Bassica juncea*) cropping sequence. *The Indian Journal of Agricultural Sciences* **78**, 1028-1032.

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.

OECD and Food and Agriculture Organization of the United Nations (2020) https://doi.org/10.1787/1112c23b-en.

Olsen, S.R., Cole, C.V., Watanabe, F.S. and Dean, L.A. (1954) Estimation of available phosphorus in soils by extraction with sodium bicarbonate. *United States Department of Agriculture Circular* No. 939.

Rathod, D.D., Rathod, P.H., Patel, K.P. and Patel, K.C. (2013) Integrated use of organic and inorganic inputs in wheat-fodder maize cropping sequence to improve crop yields and soil properties. *Archives of Agronomy and Soil Science* **59**, 1439-1455.

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**, 632-641.

Subbiah, B.V. and Asija, G.L. (1956) A rapid procedure for the estimation of available nitrogen in soils. *Current Science* **25**, 259-260.

Swain, A., Singh, S.K., Mohapatra, K. and Patra, A. (2020) Effect of sewage sludge application on yield, nutrients uptake and nutrient use efficiency of spinach (*Spinacia oleracea L.*). *Annals of Plant and Soil Research* **22**, 305-309.

Verma, A.K., Meena, M.C., Datta, S.P., Dwivedi B.S., Golui, D., Kumar, A., Louhar, G. and Meena, R.K. (2021) Impact of long-term sludge application on yield, nutrient uptake and profitability of maize (*Zea mays*). *Indian Journal of Agricultural Sciences* **91**, 137-141.

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 (*Oryza sativa*) in sludge treated soil. *Indian Journal of Agricultural Sciences* **90**, 1310-1314.

Walkley, A. and Black, I.A. (1934) An examination of the Degtjareff method for determining soil organic matter, and a proposed modification of the chromic acid titration method. *Soil Science* **37**, 29-38.

Yadav, M.R., Kumar, Y., Pooniya, V., Gupta, K.C., Saxena, R., Garg, N.K. and Singh, A. (2019) Performance of groundnut (*Arachis hypogaea*) under different phosphorus management options in semi-arid environment of Rajasthan. *Indian Journal of Agricultural Sciences* **89**, 946-950.

Zuo, W., Gu, C., Zhang, W., Xu, K., Wang, Y., Bai, Y., Shan, Y. and Dai, Q. (2019) Sewage sludge amendment improved soil properties and sweet sorghum yield and quality in a newly reclaimed mudflat land. *Science of the Total Environment* **654**, 541-549.

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