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Effect of NPK and sewage sludge on the physico chemical properties of soil for fenugreek (*Trigonella foenum-graecum*) var. bold inoculated with rhizobium and phosphorus solubilizing bacteria at Prayagraj

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Abstract

Nitrogen (N), phosphorus (P), and potassium (K) are essential macro nutrients vital for optimal plant health and crop yields. Maintaining the right balance of NPK in soil is crucial for plant growth and agricultural productivity. This research examines the effects of NPK fertilizers and sewage sludge on soil physico chemical properties for fenugreek (*Trigonella foenum-graecum*) in Prayagraj. The experiment tested various NPK levels and sewage sludge amounts, measuring soil pH, electrical conductivity, organic content, and nutrient availability. Results show that combining NPK fertilizers with sewage sludge significantly improves soil quality and structure. The inclusion of bio-fertilizers enhanced nutrient uptake, notably nitrogen and phosphorus, fostering better growth and higher-quality seed production in fenugreek compared to controls. This study highlights the potential of integrating chemical and organic amendments with bio-fertilizers to sustainably increase crop production, suggesting that such practices can significantly enhance soil health and boost agricultural output without harming the environment.

Keywords: Sewage sludge, biofertilizers, nitrogen, phosphorus, potassium and fenugreek etc.

Introduction

Soil acts as a dynamic environment hosting a vast array of living organisms. (Sofo *et al*., 2020) [35]. Fenugreek (*Trigonella foenum-graecum* L.) is a plant cultivated primarily for its seeds and leaves, which are important in both cooking and medicine. The seeds are used as a spice to add flavor to various dishes. In scientific terms, fenugreek seeds contain a variety of bioactive compounds such as alkaloids, flavonoids, saponins, and steroidal saponins, which contribute to its medicinal properties. (Dutta *et al*., 2011) [11]. As a leguminous crop, fenugreek forms a symbiotic relationship with rhizobia bacteria, enabling the conversion of atmospheric nitrogen into forms that plants can use, thereby enhancing soil fertility (Pareek and Gupta, 1981) [25]. Sewage sludge, when applied properly, offers several benefits to soil health and fertility. It is rich in organic matter and essential nutrients like nitrogen, phosphorus, and potassium, making it a valuable soil amendment. Sewage sludge improves soil structure, enhances moisture retention, and stimulates microbial activity. Its organic content helps aerate soil, reduce compaction, and promote root growth, thereby improving plant growth and yield. Additionally, sewage sludge aids in nutrient recycling, helps regulate soil pH, and serves as a cost-effective alternative to commercial fertilizers. It encourages sustainable agricultural practices and supports the recycling of waste materials. (Delibacak, Voronina, and Morachevskaya, 2020) [12].

Materials and Methods

The experiment entitled "Effect of NPK and Sewage Sludge on the Physico-Chemical Properties of Soil for Fenugreek (Trigonella foenum-graecum) Var. Bold Inoculated with Rhizobium and Phosphorus Solubilizing Bacteria" was conducted at the Soil Science Research Farm, SHUATS, Prayagraj, during the Rabi season of 2023. Situated in the Agro-Ecological Sub Region of the North Alluvium Plain Zone, the farm experiences a subtropical climate characterized by extreme temperatures ranging from below 4 °C in winter to up to 46 °C in summer, with an annual rainfall of approximately 1100 mm. Soil samples for this study were collected at two depths, 0-15 and 15-30 cm.

The research involved the application of three levels of NPK (0%, 50%, 100%) and sewage sludge (0%, 15%, 30%), along with a single level (100%) of Rhizobium and Phosphorus Solubilizing Bacteria (PSB). The experiment aimed to observe the physical and chemical parameters of the soil.

The study measured physical parameters such as bulk density (Mg m^{-3}), particle density (Mg m^{-3}), percent pore space, and percent water holding capacity using the method described by with a 100 ml graduated measuring cylinder. Chemical parameters measured included pH, electrical conductivity (dS m^{-1}), percent organic carbon, and available nitrogen, phosphorus, and potassium (Kg ha^{-1}). These measurements followed the methods of, respectively. The data collected during the investigation were analyzed using a randomized block design, employing the Analysis of Variance technique as described.

Results and Discussion

The combination of sewage sludge with rhizobium and phosphorus solubilizing bacteria (biofertilizers) markedly enhanced soil properties. These enhancements led to improved the pore space, water holding capacity, organic carbon and availability of key nutrients like nitrogen, phosphorus and potassium.

Physical properties

The data showed in table 1, clearly shows as influenced by NPK and sewage sludge conjugated with bio-fertilizers soil properties such as bulk density (Mg m^{-3}), particle density (Mg m^{-3}), percent pore space and percent water holding capacity of soil at 0-15 and 15-30 cm depth. The maximum bulk density of soil 1.26 and 1.26 Mg m^{-3} was recorded in treatmentT_1 (@ 0% NPK + 0t SS + 0) , while minimum bulk density of soil 1.24 and 1.24 Mg m^{-3} was recorded in treatment T_{18} (@ 100% NPK + 30t SS + Rh), respectively.The inclusion of organic matter from sewage sludge and increased microbial activity due to Rhizobium likely contributed to the reduction in bulk density by improving soil structure and porosity. Similar observation were recorded by Clapp *et al*., (1986) [9].

The maximum particle density of soil 2.49 and 2.49 Mg m^{-3} was recorded in treatment T_1 (@ 0% NPK + 0t SS + 0), while minimum particle density of soil 2.41 and 2.41 Mg m^{-3} was recorded in treatment T_{18} (@ 100% NPK + 30t SS + Rh, respectively. The reduction in particle density in treatment T_{18} can be attributed to the higher levels of organic matter from sewage sludge and the presence of Rhizobium, which enhance microbial activity, soil aeration, water retention, and nutrient availability. These factors collectively contribute to a lower particle density in the soil. Similar observation were recorded by Badaou, and Sahin, (2022) [7].

The maximum pore space of soil 46.94 and 42.44 Mg m^{-3} was recorded in treatment T_{18} (@ 100% NPK + 30t SS + Rh), while minimum pore space of soil 41.33 and 40.65 Mg m^{-3} was recorded in treatment T_1 (@ 0% NPK + 0t SS + 0), respectively. The presence of sewage sludge and biofertilizers may act as Organic matter decomposition creates stable aggregates, enhancing soil porosity and increasing % pore space. Similar observation were recorded by Badaou, and Sahin, (2022) [7].

The maximum water holding capacity of soil 45.61 and 44.76 Mg $m^{-3}$was recorded in treatment T_{18} (@ 100% NPK + 30t SS + Rh), while minimum water holding capacity of soil 41.12 and 40.55 Mg m^{-3} was recorded in treatment T_1 (@ 0% NPK + 0t SS + 0), respectively. The addition of Sewage sludge and biofertilizers with seed inoculation to the soil enhance porosity and stabilize the soil matrix, thereby improving water retention.Similar observation were recorded by Abdoli, (2022) [1].

Chemical properties

The data showed in table 2, clearly shows as influenced by NPK and sewage sludge conjugated with bio-fertilizers soil properties such as pH, electrical conductivity, percent organic carbon, available nitrogen, phosphorus and potassium at 0-15 and 15-30 cm depth, was found significant. The maximum pH of soil 7.55 and 7.57 was recorded in treatment T_1 (@ 0% NPK + 0t SS + 0), while minimum pH of soil 7.25 and 7.28 was recorded in treatment T_{18} (@ 100% NPK + 30t SS + Rh), respectively. Due to the decomposition of organic matter, nitrification, cation exchange, and the presence of heavy metals. The process involves the production of organic acids, release of hydrogen ions during nitrification, and displacement of cations, all contributing to soil acidification. Similar observation were recorded by Eid *et al*., (2017) [14]; and Singh and Agrawal (2013) [38].

The maximum electrical conductivity of soil 0.320 and 0.322 dS m^{-1} at 0-15 and 15-30 cm was recorded in treatment T_{18} (@ 100% NPK + 30t SS + Rh), while minimum electrical conductivity of soil 0.285 and 0.291 dS m^{-1} was recorded in treatment T_1 (@ 0% NPK + 0t SS + 0), respectively. The application of sewage sludge increases soil electrical conductivity primarily due to the addition of soluble salts, nutrients, organic matter decomposition, heavy metal release, and enhanced microbial activity. Similar observation were recorded by Hussein, (2009) [18] and Samaras *et al*., (2008) [31].

The maximum percent organic carbon of soil 0.47 and 0.46 was recorded in treatment T_{18} (@ 100% NPK + 30t SS + Rh), while minimum organic carbon (%) of soil 0.40 and 0.39 was recorded in treatment T_1 (@ 0% NPK + 0t SS + 0), respectively.The application of organic fertilizers, including municipal sewage sludge compost, has been shown to increase organic carbon values compared to NPK fertilizers. Similar observation were recorded by Richardson *et al*., (2009) [29] and Pena *et al*., (2015) [26].

The maximum available nitrogen of soil 286.97 and 285.54 Kg ha^{-1} was recorded in treatment T_{18} (@ 100% NPK + 30t SS + Rh), while minimum available nitrogen of soil 270.23 and 266.11 Kg ha^{-1} was recorded in treatment T_1 (@ 0% NPK + 0t SS + 0), respectively. Sewage sludge, rich in organic and inorganic nitrogen compounds, increases soil nitrogen content when applied. Similar observation were recorded by Upadhyay *et al*., (2013 and Mohamed *et al*., (2018) [38, 24].

The maximum available phosphorus of soil 18.98 and 18.97 Kg ha^{-1} was recorded in treatment T_{18} (@ 100% NPK + 30t SS + Rh), while minimum available phosphorus of soil 15.10 and 14.07 Kg ha^{-1} was recorded in treatment T_1 (@ 0% NPK + 0t SS + 0), respectively. Organic phosphorus in sewage sludge undergoes mineralization, converting into inorganic forms like orthophosphate, which are available for plant uptake, thus enriching the soil with phosphorus. Similar observation were recorded by Soon, (1981) [36].

The maximum available potassium of soil 166.54 and 165.21 Kg ha^{-1} was recorded in treatment T_{18} (@ 100% NPK + 30t SS + Rh), while minimum potassium of soil 150.32 and 147.11 Kg ha^{-1} was recorded in treatment T_1 (@ 0% NPK + 0t SS + 0), respectively.Potassium improves a plant's ability to withstand various stresses, including drought, cold, and salinity. Similar observation were recorded by You *et al.*, 2019 and Hussein, (2009) [18].

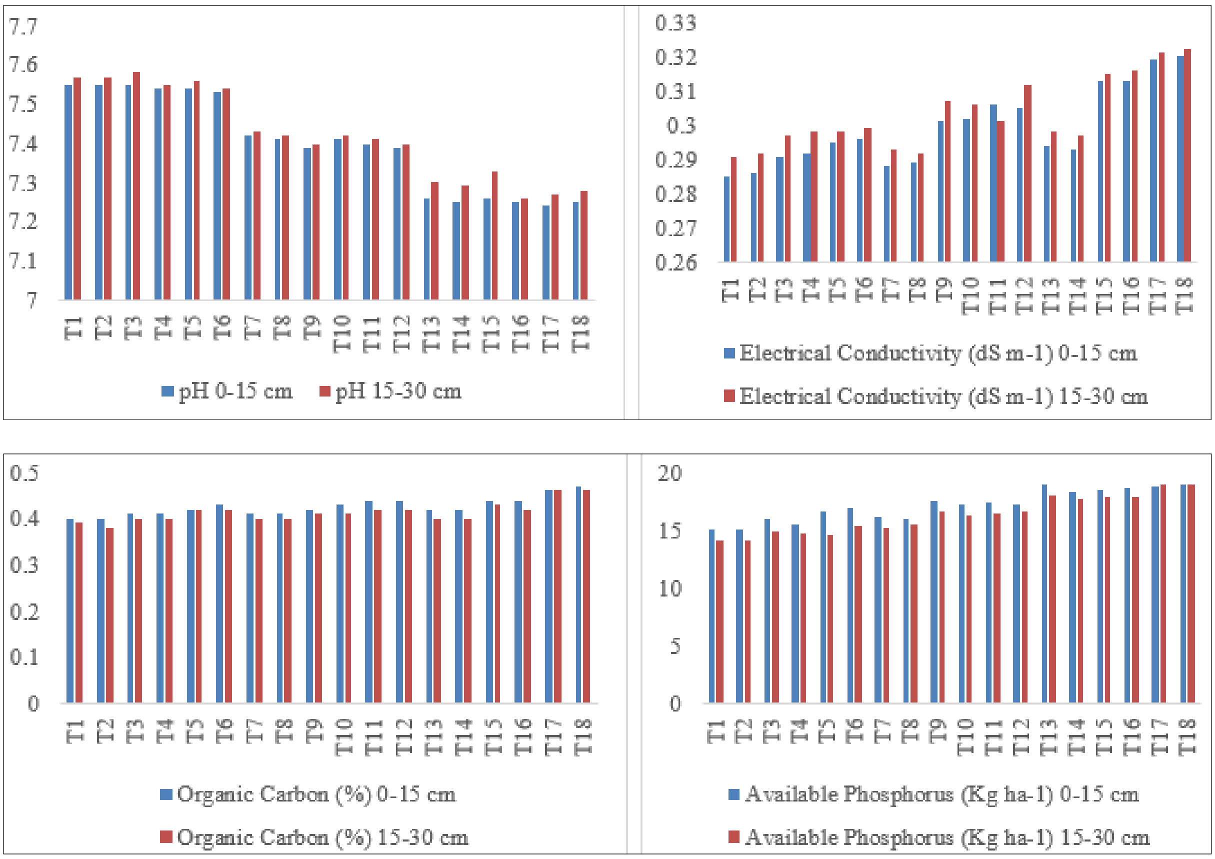
Table 1: Effect of NPK and sewage sludge conjugated with bio-fertilizers on bulk density (Mg m^{-3}), particle density (Mg m^{-3}), % pore space and % water holding capacity of soil at 0-15 and 15-30 cm depth

Treatment	Bulk Density (Mg m^{-3})		Particle Density (Mg m^{-3})		% Pore Space		Water Holding Capacity (%)	
	0-15 cm	15-30 cm	0-15 cm	15-30 cm	0-15 cm	15-30 cm	0-15 cm	15-30 cm
T_1	1.26	1.26	2.49	2.49	41.33	40.65	41.12	40.55
T_2	1.25	1.26	2.49	2.49	41.12	40.61	41.13	40.63
T_3	1.25	1.25	2.48	2.48	42.36	41.17	41.97	40.79
T_4	1.25	1.25	2.48	2.48	42.08	41.73	41.78	40.42
T_5	1.23	1.25	2.45	2.48	43.20	41.16	42.15	41.06
T_6	1.24	1.25	2.45	2.48	43.55	42.38	42.13	41.38
T_7	1.25	1.26	2.47	2.47	41.23	40.49	42.26	41.00
T_8	1.25	1.26	2.47	2.46	42.29	40.14	42.25	41.53
T_9	1.25	1.25	2.46	2.46	43.08	41.06	43.06	42.97
T_{10}	1.25	1.25	2.46	2.47	43.23	41.18	43.10	42.86
T_{11}	1.24	1.25	2.43	2.44	45.10	42.34	44.08	42.01
T_{12}	1.24	1.25	2.42	2.43	45.28	42.28	44.10	43.72
T_{13}	1.25	1.26	2.45	2.45	42.64	41.73	42.90	41.86
T_{14}	1.25	1.25	2.45	2.46	42.36	40.53	42.87	41.80
T_{15}	1.25	1.25	2.44	2.45	44.37	40.82	43.98	42.99
T_{16}	1.25	1.25	2.44	2.44	44.21	42.77	44.04	43.85
T_{17}	1.24	1.25	2.42	2.43	46.27	42.71	45.65	44.62
T_{18}	1.24	1.24	2.41	2.41	46.94	42.44	45.61	44.76
F-Test	NS	NS	NS	NS	S	S	S	S
S.Ed. (±)	-	-	-	-	0.81	0.64	0.81	0.64
C.D. at 0.5%	-	-	-	-	0.12	0.10	0.12	0.10

Table 2: Effect of NPK and sewage sludge conjugated with bio-fertilizers on soil pH, electrical conductivity (dS m^{-1}), organic carbon (%), available nitrogen (Kg ha^{-1}), available phosphorus (Kg ha^{-1}), and available potassium (Kg ha^{-1}) of soil at 0-15 and 15-30 cm depth

Treatment	pH		Electrical Conductivity (dS m^{-1})		Organic Carbon (%)		Available Nitrogen (Kg ha^{-1})		Available Phosphorus (Kg ha^{-1})		Available Potassium(Kg ha^{-1})	
	0-15 cm	0-15 cm	0-15 cm	15-30 cm	0-15 cm	15-30 cm	0-15 cm	15-30 cm	0-15 cm	15-30 cm	0-15 cm	15-30 cm
T_1	7.55	7.57	0.285	0.291	0.40	0.39	270.23	266.11	15.10	14.07	150.32	147.11
T_2	7.55	7.57	0.286	0.292	0.40	0.38	270.31	266.36	15.09	14.18	150.80	147.32
T_3	7.55	7.58	0.291	0.297	0.41	0.40	271.11	267.12	15.95	14.92	151.35	148.12
T_4	7.54	7.55	0.292	0.298	0.41	0.40	271.14	267.13	15.58	14.70	151.08	147.08
T_5	7.54	7.56	0.295	0.298	0.42	0.42	272.11	268.56	16.58	14.54	152.75	149.89
T_6	7.53	7.54	0.296	0.299	0.43	0.42	272.26	268.57	16.95	15.32	152.09	149.28
T_7	7.42	7.43	0.288	0.293	0.41	0.40	273.21	271.68	16.10	15.14	154.90	151.74
T_8	7.41	7.42	0.289	0.292	0.41	0.40	273.32	271.11	16.02	15.52	154.32	151.97
T_9	7.39	7.40	0.301	0.307	0.42	0.41	275.12	273.36	17.54	16.58	156.21	154.14
T_{10}	7.41	7.42	0.302	0.306	0.43	0.41	275.32	273.54	17.21	16.25	156.32	156.54
T_{11}	7.40	7.41	0.306	0.301	0.44	0.42	277.62	275.10	17.36	16.39	158.56	156.23
T_{12}	7.39	7.40	0.305	0.312	0.44	0.42	277.69	275.80	17.21	16.54	158.21	156.84
T_{13}	7.26	7.30	0.294	0.298	0.42	0.40	280.36	278.12	18.95	17.97	161.45	159.58
T_{14}	7.25	7.29	0.293	0.297	0.42	0.40	280.59	278.31	18.31	17.65	161.54	159.68
T_{15}	7.26	7.33	0.313	0.315	0.44	0.43	283.98	281.21	18.54	17.84	163.78	161.86
T_{16}	7.25	7.26	0.313	0.316	0.44	0.42	283.32	281.36	18.68	17.87	163.58	161.31
T_{17}	7.24	7.27	0.319	0.321	0.46	0.46	286.56	285.35	18.78	18.87	166.65	165.54
T_{18}	7.25	7.28	0.320	0.322	0.47	0.46	286.97	285.54	18.98	18.97	166.54	165.21
F-Test	S	S	S	S	S	S	S	S	S	S	S	S
S.Ed. (±)	0.040	0.032	0.007	0.004	0.012	0.013	13.03	13.03	0.66	0.66	8.17	8.17
C.D. at 0.5%	0.038	0.030	0.116	0.066	0.183	0.206	27.62	27.62	1.39	1.39	17.32	17.32

Fig 1: Graphical representation of bulk density (Mg m^{-3}), particle density (Mg m^{-3}), % pore space and % water holding capacity of soil on application of different treatments



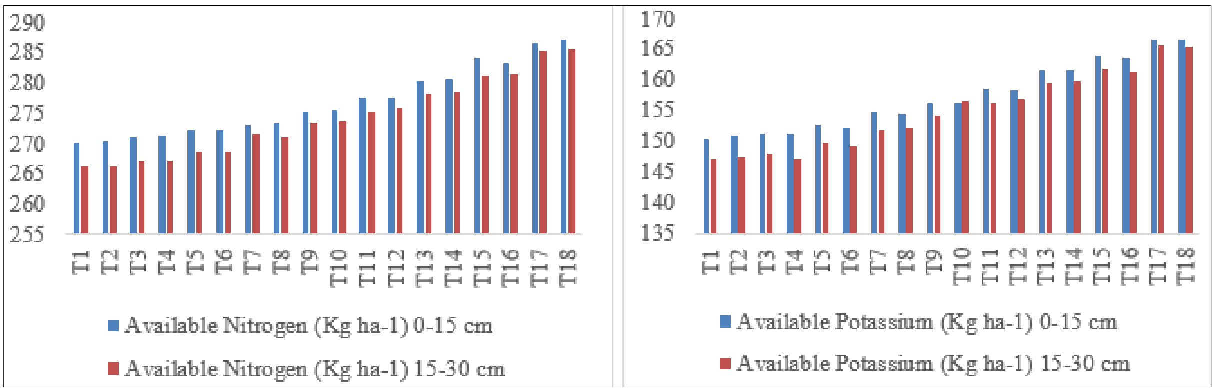


Fig 2: Graphical representation of soil pH, electrical conductivity (dSm^{-1}), organic carbon and nitrogen, phosphorus, potassium of soil on application of different treatments.

Conclusion

The study demonstrates that the combination of NPK, sewage sludge, and biofertilizers (Rhizobium and phosphorus solubilizing bacteria) significantly enhances soil physical and chemical properties. Treatment T_{18} (100% NPK + 30t SS + Rh) yielded the best results, with maximum improvements in bulk density, particle density, pore space, water holding capacity, electrical conductivity, organic carbon, and nutrient availability (nitrogen, phosphorus, and potassium). Conversely, the control treatment T_1 (0% NPK + 0t SS + 0) showed the least improvement. These findings highlight the effectiveness of integrating NPK, sewage sludge, and biofertilizers in enhancing soil health and fertility.

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References

1. Abdoli M. Sustainable Use of *Sewage Sludge* in Soil Fertility and Crop Production. In: Sustainable Management and Utilization of Sewage Sludge; c2022. p. 297-333.
2. Abawari RA, Tuji FA, Yadete DM. Phosphate solubilizing bio-fertilizers and their role in bio-available P nutrient: an overview. Int J Appl Agric Sci. 2020;6(6):162.
3. Al-Hadithi GS, Faleh N, Al-Saady HA. Effect of different fertilizers on growth and nutrient state of fenugreek (*Trigonella foenum–graecum* L.).
4. Al-Jenoobi FI, Al-Suwayeh SA, Muzaffar I, Alkharfy KM, Al-Mohizea AM, Al-Suwayeh R. Evaluation of the permeability and anti-inflammatory activity of a novel fenugreek seed extract. Food Chem Toxicol. 2013;62:786-796.
5. Aleminew A, Alemayehu M. Soil fertility depletion and its management options under crop production perspectives in Ethiopia: A review. Agric Rev. 2020;41(2):91-105.
6. Anwar S, Nawaz MF, Gul S, Rizwan M, Ali S, Kareem A. Uptake and distribution of minerals and heavy metals in commonly grown leafy vegetable species irrigated with sewage water. Environ Monit Assess. 2016;188:1-9.
7. Badaou AAD, Sahin U. Effects of sewage sludge amendment and wetting–drying cycles of wastewater irrigation on structural improvement of clay soil. Int J Environ Sci Technol. 2022;19(7):6453-6466.
8. Bouyoucos GJ. A new method for the determination of hygroscopic moisture in soils. Soil Sci. 1927;24(4):317-325.
9. Clapp CE, Stark SA, Clay DE, Larson WE. Sewage sludge organic matter and soil properties. In: *The role of organic matter in modern agriculture*. 1986:209-253.
10. Datta N, Hore JK. Effect of nitrogen, phosphorus and potassium on growth and yield of fenugreek (*Trigonella foenum-graecum* L.).
11. Dutta B, Pariari A, Debnath A, Khan S. Response of fenugreek (*Trigonella foenum-graecum*) to different levels of nitrogen and Rhizobium. J Crop Weed. 2011;7(2):28-29.
12. Delibacak S, Voronina L, Morachevskaya E. Use of sewage sludge in agricultural soils: Useful or harmful. Eur J Soil Sci. 2020;9(2):126-139.
13. Dhadse S. Vermiconversion of textile industrial sludge; waste management and nutrients recycling. IntechOpen; c2022.
14. Eid EM, El-Bebany AF, Alrumman SA, Hesham AEL, Taher MA, Fawy KF. Effects of different sewage sludge applications on heavy metal accumulation, growth and yield of spinach (*Spinacia oleracea* L.). Int J Phytoremediation. 2017;19(4):340-347.
15. Eissa AHA, Palomino OM, Carretero ME, Gómez-Serranillos MP. Ethnopharmacological, phytochemical and pharmacological study of traditionally used plants in the treatment of respiratory disorders in the Mediterranean region – A review. Phytother Res. 2015;29(8):1208-1218.
16. Fatima B, Bibi F, Ali MI, Woods J, Ahmad M, Mubashir M, et al. Accompanying effects of sewage sludge and pine needle biochar with selected organic additives on the soil and plant variables. Waste Manag. 2022;153:197-208.
17. Gaur VK, Sharma P, Sirohi R, Awasthi MK, Dussap CG, Pandey A. Assessing the impact of industrial waste on environment and mitigation strategies: A comprehensive review. J Hazard Mater. 2020;398:123019.
18. Hussein AHA. Impact of sewage sludge as organic manure on some soil properties, growth, yield and

nutrient contents of cucumber crop. J Appl Sci. 2009;9(8):1401-1411.
19. Lambers H, Plaxton WC. Phosphorus: back to the roots. Annu Plant Rev. 2015;48:1-22.
20. Liu Y, Kakani R, Nair MG. Compounds in functional food fenugreek spice exhibit anti-inflammatory and antioxidant activities. Food Chem. 2012;131:1187-1192.
21. Leghari SJ, Wahocho NA, Laghari GM, HafeezLaghari A, MustafaBhabhan G, HussainTalpur K, et al. Role of nitrogen for plant growth and development: A review. Adv Environ Biol. 2016;10(9):209-219.
22. Lopez G, Ahmadi SH, Amelung W, Athmann M, Ewert F, Gaiser T, et al. Nutrient deficiency effects on root architecture and root-to-shoot ratio in arable crops. Front Plant Sci. 2023;13:1067498.
23. Ma K, Zhang Y, Ruan M, Guo J, Chai T. Land subsidence in a coal mining area reduced soil fertility and led to soil degradation in arid and semi-arid regions. Int J Environ Res Public Health. 2019;16(20):3929.
24. Mohamed B, Mounia K, Aziz A, Ahmed H, Rachid B, Lotfi A. Sewage sludge used as organic manure in Moroccan sunflower culture: Effects on certain soil properties, growth and yield components. Sci Total Environ. 2018;627:681-688.
25. Pareek SK, Gupta R. Effect of fertilizer application on seed yield and and diosgenin content in fenugreek. Indian J Agric Sci. 1981;50(10):746-749.
26. Pena A, Mingorance MD, Rossini-Oliva S. Soil quality improvement by the establishment of a vegetative cover in a mine soil added with composted municipal sewage sludge. J Geochem Explor. 2015;157:178-183.
27. Raj A, Yadav A, Arya S, Sirohi R, Kumar S, Rawat AP, et al. Preparation, characterization and agri applications of biochar produced by pyrolysis of sewage sludge at different temperatures. Sci Total Environ. 2021;795:148722.
28. Rao A, Steels E. The influence of fenugreek (*Trigonella foenum-graecum*) on antioxidant status in normal and streptozotocin induced diabetic rats. J Ethnopharmacol. 2011;137(3):1328-1333.
29. Richardson AE, Barea JM, McNeill AM, Prigent-Combaret C. Acquisition of phosphorus and nitrogen in the rhizosphere and plant growth promotion by microorganisms.
30. Rubilar M, Gutiérrez C, Verdugo M, Shene C, Sineiro J. Flaxseed as a source of functional ingredients. J Soil Sci Plant Nutr. 2010;10(3):373-377.
31. Samaras V, Tsadilas CD, Stamatiadis S. Effects of repeated application of municipal sewage sludge on soil fertility, cotton yield, and nitrate leaching. Agron J. 2008;100(3):477-483.
32. Sahu PK, Naruka IS, Haldar A, Chundawat RS, Kumar H. Study the effect of integrated nutrient management on vegetative growth of fenugreek (*Trigonella foenum-graecum*) L. J Pharmacogn Phytochem. 2020;9(3):1389-1394.
33. Sahu PK, Naruka IS, Haldar A, Chundawat RS, Kumar L. Studies on the effects of integrated nutrient management on fenugreek (*Trigonella foenum-graecum*) L. Int J Chem Stud. 2020;8(2):1082-1089.
34. Sardans J, Penuelas J. Potassium control of plant functions: Ecological and agricultural implications. Plants. 2021;10(2):419.
35. Sofo A, Mininni AN, Ricciuti P. Soil macrofauna: A key factor for increasing soil fertility and promoting sustainable soil use in fruit orchard agrosystems. Agronomy. 2020;10(4):456.
36. Soon YK. Solubility and sorption of cadmium in soils amended with sewage sludge. J Soil Sci. 1981;32:85-95.
37. Stewart ZP, Pierzynski GM, Middendorf BJ, Prasad PV. Approaches to improve soil fertility in sub-Saharan Africa. J Exp Bot. 2020;71(2):632-641.
38. Upadhyay S, Thomas T, Kumar S, Singh P. Effect of sewage sludge and inorganic fertilizer application on physico-chemical properties of soil and yield of carrot (*Daucus carota* L.). Asian J Soil Sci. 2013;8:202-207.
39. Vanlauwe B, AbdelGadir AH, Adewopo J, Adjei-Nsiah S, Ampadu-Boakye T, Asare R, et al. Looking back and moving forward: 50 years of soil and soil fertility management research in sub-Saharan Africa. Int J Agric Sustain. 2017;15(6):613-631.
40. Yaldiz G, Camlica M. Impact of various environmental stress factors on productivity, quality, and secondary metabolites of fenugreek (*Trigonella foenum-graecum* L.). In: *Fenugreek:* Biology and applications; c2021. p. 301-326.
41. You J, Sun L, Liu X, Hu X, Xu Q. Effects of sewage sludge biochar on soil characteristics and crop yield on loamy sand soil. Pol J Environ Stud. 2019;28:2973-2980. doi:10.15244/pjoes/93294