E-ISSN: 2618-0618
P-ISSN: 2618-060X
© Agronomy
NAAS Rating (2025): 5.20
www.agronomyjournals.com
2025; 8(12): 555-559
Received: 11-10-2025
Accepted: 17-11-2025

Snehal D Wakchaure
Department of Soil Science, Dr. PDKV, Akola, Maharashtra, India

SD Jadhao
Department of Soil Science, Dr. PDKV, Akola, Maharashtra, India

BA Sonune
Department of Soil Science, Dr. PDKV, Akola, Maharashtra, India

SM Bhoyar
Department of Soil Science, Dr. PDKV, Akola, Maharashtra, India

VK Kharche
Department of Soil Science, Dr. PDKV, Akola, Maharashtra, India

PR Kadu
Department of Soil Science, Dr. PDKV, Akola, Maharashtra, India

Sindhu R Rathod
Department of Soil Science, Dr. PDKV, Akola, Maharashtra, India

Corresponding Author:
Snehal D Wakchaure
Department of Soil Science, Dr. PDKV, Akola, Maharashtra, India

Effect of long-term manuring and fertilization on content and uptake of nutrients in wheat under sorghum-wheat cropping sequence in Vertisol

Snehal D Wakchaure, SD Jadhao, BA Sonune, SM Bhoyar, VK Kharche, PR Kadu and Sindhu R Rathod

DOI: https://www.doi.org/10.33545/2618060X.2025.v8.i12h.4451

Abstract
A field investigation was carried out at the Research Farm of the All India Coordinated Research Project on Long-Term Fertilizer Experiment (AICRP on LTFE), Dr. Panjabrao Deshmukh Krishi Vidyapeeth (Dr. PDKV), Akola, Maharashtra, India, under an ongoing long-term experiment initiated during 1988-89 in a sorghum-wheat cropping sequence on Vertisol. The study evaluated the effects of different fertilizer and nutrient management practices on nutrient content and uptake. The treatments included varying levels of the recommended dose of fertilizers (RDF) at 50, 100, and 150%, RDF combined with farmyard manure (FYM), FYM alone at 10 t ha^{-1}, RDF without sulphur, RDF supplemented with sulphur at 37.5 kg ha^{-1} and zinc at 2.5 kg ha^{-1}, NP, nitrogen alone, and an unfertilized control. The results revealed that the combined application of the optimal dose of 100% NPK along with FYM at 5 t ha^{-1} resulted in the highest nutrient concentration in both grain and straw. This treatment recorded maximum nitrogen content (1.80% in grain and 1.02% in straw), phosphorus content (0.39% in grain and 0.29% in straw), and potassium content (1.48% in grain and 0.67% in straw). Correspondingly, the highest nutrient uptake was observed under this integrated treatment, with nitrogen uptake of 65.67 and 61.98 kg ha^{-1} in grain and straw, phosphorus uptake of 16.67 and 20.64 kg ha^{-1}, and potassium uptake of 23.68 and 85.29 kg ha^{-1}, respectively, the unfertilized control treatment recorded the lowest nutrient content and uptake, with nitrogen content of 1.58% in grain and 0.69% in straw, phosphorus content of 0.31% in grain and 0.22% in straw, and potassium content of 1.30% in grain and 0.45% in straw. Nutrient uptake under the control was minimal, with nitrogen uptake of 7.72 and 7.59 kg ha^{-1}, phosphorus uptake of 2.43 and 2.43 kg ha^{-1}, and potassium uptake of 2.81 and 12.08 kg ha^{-1} in grain and straw, respectively.

Keywords: Nutrient content, nutrient uptake, FYM, Wheat, long-term fertilization

Introduction
The sorghum-wheat cropping sequence is a major production system supplying foodgrains in Peninsular Central India, particularly in Maharashtra (Katkar *et al*., 2011) [9]. Wheat (*Triticum aestivum* L.) is the second most important food grain crop in India after rice. In Maharashtra, wheat is cultivated over an area of about 1,057 thousand hectares with an annual production of approximately 2,474 thousand tonnes (Anon., 2022) [1].

Crop nutrient uptake is a key determinant of optimal fertilization practices; therefore, efficient fertilizer application is essential for improving nutrient use efficiency. Nutrient uptake and translocation within the plant system are influenced by crop growth stages, soil fertility status, and the quantity and balance of fertilizers applied. Chemical fertilizers are commonly used to supplement soil nutrient supply and enhance crop yields; however, inadequate and imbalanced fertilizer application can adversely affect soil health and lead to declining crop productivity (Kalhapure *et al*., 2014) [8].

The sustainability of any cropping system largely depends on efficient resource utilization, particularly the balanced use of organic manures and inorganic fertilizers. The conjoint application of organic manures and chemical fertilizers has emerged as a viable strategy for sustaining productivity in cereal-based cropping systems, especially under intensive cultivation and the heavy nutrient demand of the sorghum-wheat sequence, which often leads to depletion

of both macro- and micronutrients (Mali *et al*., 2015) [17]. As cereal-cereal cropping systems are known to exhaust soil nutrients rapidly, appropriate interventions are necessary to maintain nutrient balance and soil fertility.

Although direct application of organic manures to wheat is less common due to constraints related to decomposition and nutrient release, integration of organic and inorganic nutrient sources can ensure a balanced and timely supply of nutrients in optimum proportions. Farmyard manure (FYM) is a valuable, renewable organic nutrient source, and substantial quantities of organic residues available with farmers can be effectively utilized to complement chemical fertilizers (Kumari *et al*., 2017) [13]. Soil organic matter serves as a major reservoir of carbon and essential plant nutrients, playing a crucial role in nutrient availability and uptake by crops (Wang *et al*., 2015) [28].

Therefore, studying the long-term influence of organic manure and inorganic fertilizer application is essential for understanding nutrient uptake dynamics and sustaining productivity under the sorghum-wheat cropping sequence.

Material and Methods

Site description

A long-term field experiment under a sorghum-wheat cropping sequence was initiated during 1988-89 at the research farm of the All India Coordinated Research Project on Long-Term Fertilizer Experiment (AICRP on LTFE), Dr. Panjabrao Deshmukh Krishi Vidyapeeth (Dr. PDKV), Akola, Maharashtra. The experimental site is located at 22°42′ N latitude and 77°02′ E longitude, at an elevation of 307.42 m above mean sea level, and falls under a hot semi-arid agro-ecological region. The area receives the majority of its annual rainfall from the southwest monsoon.

The soil at the experimental site belongs to the Typic Haplustert group of Vertisols, characterized by montmorillonitic clay mineralogy and classified as hyperthermic (Ravankar *et al*., 1998) [19]. The soil exhibits typical swell-shrink properties associated with smectitic clays. The initial soil properties recorded at the commencement of the experiment during the kharif season of 1988 indicated that the soil was slightly alkaline in reaction (pH 8.1), medium in organic carbon content (4.60 g kg^{-1}), and moderately calcareous (5.7%). The soil was low in available nitrogen (120 kg ha^{-1}), medium in available phosphorus (8.40 kg ha^{-1}), and very high in available potassium (358 kg ha^{-1}). Available sulphur content was just above the critical limit (11.80 mg kg^{-1}), while DTPA-extractable zinc was marginal (0.62 mg kg^{-1}).

Experimental design, treatment details and crop management

The present study forms part of a long-term fertilizer experiment being conducted continuously at the same site since 1988-89 without altering the original treatment randomization. The experiment was carried out under rainfed conditions at the farm of the All India Coordinated Research Project on Long-Term Fertilizer Experiment (AICRP on LTFE), Dr. Panjabrao Deshmukh Krishi Vidyapeeth (Dr. PDKV), Akola, Maharashtra, India. The experiment was laid out in a Randomized Block Design (RBD) comprising twelve treatments with three replications (Table 1).

Wheat cultivar AKW 4627 was sown during the second fortnight of November each year. Farmyard manure (FYM), wherever included as a treatment component, was applied annually one month prior to sowing of the preceding sorghum crop. The recommended fertilizer dose for wheat was 120:60:60 kg $N:P_2O_5:K_2O$ ha^{-1}. Half of the nitrogen dose (60 kg ha^{-1}) along with the full doses of phosphorus and potassium was applied at sowing, while the remaining half of nitrogen was top-dressed at 21 days after sowing (DAS).

Gypsum was applied as a source of sulphur in treatment T_9 for both crops, whereas zinc sulphate ($ZnSO_4$) was applied as a source of zinc in treatment T_5. All other agronomic practices were followed as per the standard package of practices recommended by the university.

Table 1: Treatment details under long-term fertilizer experiment

Treatment	Treatment details	
	***Kharif* (Sorghum)**	***Rabi* (Wheat)**
T_1	50% NPK	50% NPK
T_2	100% NPK	100% NPK
T_3	150% NPK	150% NPK
T_4	100% NPK (S free)	100% NPK (S free)
T_5	100% NPK	100% NPK + Zn @2.5 kg ha^{-1}
T_6	100% NP	100% NP
T_7	100% N	100% N
T_8	100% NPK + FYM @ 5 t ha^{-1}	100% NPK
T_9	100% NPK + S @ 37.5 kg ha^{-1}	100% NPK + S @ 37.5 kg ha^{-1}
T_{10}	FYM @ 10 t ha^{-1}	FYM @ 10 t ha^{-1}
T_{11}	75% NPK + 25% N through FYM	75% NPK + 25% N through FYM
T_{12}	Control (no manures and fertilizer)	Control (no manures and fertilizer)

Note: *T_5: treatment the Zn application on the basis of soil test value *T_8: treatment the dose of FYM from 10 t ha^{-1} was reduced to 5 t ha^{-1}, *T_{10}: treatment the dose of FYM @ 10 t ha^{-1} was applied to sorghum and wheat crop *T_{11}: the application of 75% NPK + 25% N through FYM was started to apply from 2011-12.

Plant analysis and calculations of nutrient uptake

The plant samples were air-dried in shade and digested by using a di-acid and tri-acid mixture. Total N was analyzed by Micro-Kjeldahl method (Jackson, 1973) [6], Total P by Vanadomolybdate yellow colour method (Jackson, 1973) [6] and Total K by Flame photometry (Jackson, 1973) [6]. The uptake of major nutrients was worked out by multiplying total dry matter and nutrient concentration.

Statistical Analysis

The data were statistically analysed by the technique of analysis of variance (ANOVA) as suggested by Gomez and Gomez, (1984) [3].

Results and Discussion

Nutrient content

The data illustrating the effects of long-term fertilization in

conjunction with farmyard manure (FYM) on nitrogen, phosphorus, and potassium content in grain and straw are presented in Table 2. The nitrogen content in grain ranged from 1.58 to 1.80%, while in straw it varied from 0.69 to 1.02%. Phosphorus content in grain ranged from 0.31 to 0.41%, whereas in straw it ranged from 0.22 to 0.29%. Similarly, potassium content in grain varied from 1.30 to 1.48%, and in straw from 0.45 to 0.67%.

Perusal of the data revealed that application of 100% NPK in combination with FYM at 5 t ha^{-1} resulted in the highest N, P, and K contents in both grain (1.80% N, 0.41% P, and 1.48% K) and straw (1.02% N, 0.29% P, and 0.67% K). The enhanced nutrient content under integrated nutrient management may be attributed to improved root development and increased availability of nutrients in the root zone, facilitating greater nutrient absorption by the crop (Jat *et al*., 2007) [7].

Furthermore, the combined application of inorganic fertilizers and FYM was more effective than sole application of either source, likely because inorganic fertilizers supply readily available nutrients during early vegetative growth, while FYM contributes to sustained nutrient release through gradual mineralization over the crop growth period (Goutami and Rani, 2016) [4]. Farmyard manure also plays a crucial role in supplying essential nutrients and improving nutrient use efficiency (Tolba *et al*., 2003; Khater *et al*., 2004) [23, 11]. These findings are consistent with earlier reports by Malav *et al*. (2019) [14] and Puli *et al*. (2012) [18], who observed higher nutrient content in crops following the application of optimal doses of NPK in conjunction with FYM.

Nutrient uptake

The data pertaining to nitrogen, phosphorus, and potassium uptake by wheat grain and straw as influenced by continuous application of fertilizers and manures are presented in Table 3. Nitrogen uptake by grain ranged from 7.72 to 65.67 kg ha^{-1}, while uptake by straw varied from 7.59 to 61.98 kg ha^{-1}. Significantly higher nitrogen uptake by both grain (65.67 kg ha^{-1}) and straw (61.98 kg ha^{-1}) was recorded in the treatment receiving 100% NPK in combination with FYM at 5 t ha^{-1} (T_8), whereas the lowest uptake was observed in the unfertilized control. These results are in agreement with the findings of Chesti *et al*. (2013) [2], who attributed higher nitrogen uptake in wheat to enhanced nutrient availability and improved metabolic activity under integrated nutrient management.

Phosphorus uptake by grain ranged from 2.43 to 16.67 kg ha^{-1}, while uptake by straw varied from 2.43 to 20.67 kg ha^{-1}. The highest phosphorus uptake by grain (16.67 kg ha^{-1}) and straw (20.67 kg ha^{-1}) was also recorded under the integrated treatment T_8, whereas the control treatment exhibited the lowest uptake. The increased phosphorus uptake with FYM application may be attributed to the solubilization of native soil phosphorus and mineralization of organically bound phosphorus, thereby enhancing its availability to plants (Sharma *et al*., 2016) [21].

Potassium uptake by grain ranged from 2.81 to 23.68 kg ha^{-1}, and uptake by straw from 12.08 to 85.29 kg ha^{-1}. The combined application of optimal NPK fertilization with FYM (T_8) resulted in significantly higher potassium uptake by both grain (23.68 kg ha^{-1}) and straw (85.29 kg ha^{-1}). This increased uptake may be ascribed to greater potassium availability from both fertilizers and organic sources, along with improved root proliferation that enhanced nutrient absorption (Kumari *et al*., 2017) [13].

Overall, the results indicate that balanced application of chemical fertilizers in conjunction with FYM significantly enhanced the uptake of nitrogen, phosphorus, and potassium by wheat. This improvement may be largely attributed to increased biomass production and improved nutrient availability throughout the crop growth period. Inorganic nitrogen not only supplies readily available nitrogen for plant growth but also stimulates mineralization of native and applied organic matter by meeting the nitrogen requirements of soil microorganisms (Goutami and Rani, 2016) [4]. Similar observations have been reported by Malav *et al*. (2019) [14], Venugopal *et al*. (2017) [27], Sharma *et al*. (2010) [20], and Thakur and Sawarkar (2009) [22], who consistently reported higher nutrient uptake under integrated nutrient management practices in long-term experiments on Vertisols.

Table 2: Effect of long-term manuring and fertilization on nutrient content of wheat

Treatments details		Nutrient content (%)					
		Grain			Straw		
		N	P	K	N	P	K
T_1	50% NPK	1.62	0.32	1.33	0.75	0.26	0.49
T_2	100% NPK	1.70	0.36	1.40	0.87	0.27	0.57
T_3	150% NPK	1.78	0.39	1.47	0.99	0.29	0.65
T_4	100% NPK (S free)	1.68	0.35	1.38	0.84	0.27	0.55
T_5	100% NPK + Zn @ 2.5 kg ha^{-1}	1.72	0.37	1.42	0.90	0.28	0.59
T_6	100% NP	1.66	0.34	1.36	0.81	0.27	0.53
T_7	100% N	1.60	0.31	1.31	0.72	0.25	0.47
T_8	100% NPK + FYM @ 5 t ha^{-1}	1.80	0.39	1.48	1.02	0.29	0.67
T_9	100% NPK + S @ 37.5 kg ha^{-1}	1.74	0.41	1.43	0.93	0.28	0.61
T_{10}	FYM @ 10 t ha^{-1}	1.64	0.33	1.35	0.78	0.26	0.51
T_{11}	75% NPK + 25% N through FYM	1.76	0.38	1.45	0.96	0.28	0.63
T_{12}	Control (no manures and fertilizer)	1.58	0.31	1.30	0.69	0.22	0.45
SE (m) ±		0.05	0.03	0.05	0.07	0.01	0.01
CD at 5%		0.14	0.08	0.14	0.22	0.026	0.02

Table 3: Effect of long-term manuring and fertilization on nutrient uptake by wheat

Treatments details		Nutrient uptake (kg ha^{-1})					
		Grain			Straw		
		N	P	K	N	P	K
T_1	50% NPK	23.94	4.37	7.56	20.89	5.73	33.19
T_2	100% NPK	46.29	9.62	15.44	40.32	11.38	60.49
T_3	150% NPK	57.99	14.02	20.62	52.56	17.01	73.39
T_4	100% NPK (S free)	41.56	8.32	13.64	37.16	10.12	56.79
T_5	100% NPK + Zn @ 2.5 kg ha^{-1}	48.22	10.41	16.39	43.92	13.01	64.75
T_6	100% NP	34.37	6.56	11.05	29.63	7.64	46.49
T_7	100% N	11.84	2.78	3.58	9.07	3.57	15.11
T_8	100% NPK + FYM @ 5 t ha^{-1}	65.67	16.67	23.68	61.98	20.64	85.29
T_9	100% NPK + S @ 37.5 kg ha^{-1}	51.64	11.53	17.81	47.53	14.56	68.93
T_{10}	FYM @ 10 t ha^{-1}	27.97	4.67	8.65	24.43	5.52	39.64
T_{11}	75% NPK + 25% N through FYM	53.14	12.26	18.62	51.68	16.21	73.25
T_{12}	Control	7.72	2.43	2.81	7.59	2.43	12.08
SE (m) ±		1.79	0.39	0.67	1.68	0.71	2.62
CD at 5%		5.25	1.16	2.02	4.93	2.07	7.69

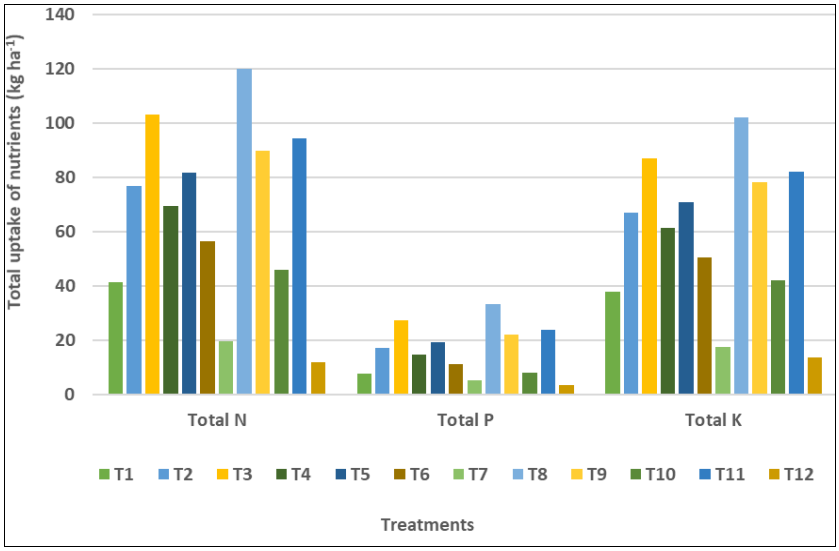

Fig 1: Effect of long-term manuring and fertilization on total uptake of nutrients by wheat in sorghum-wheat sequence

Conclusion

The results of the long-term fertilizer experiment clearly indicate that balanced application of the optimal dose of NPK in conjunction with organic manure is a suitable and sustainable nutrient management practice for wheat cultivation under the sorghum-wheat cropping sequence. Integrated use of chemical fertilizers with farmyard manure significantly enhanced nitrogen, phosphorus, and potassium content in both grain and straw, which subsequently resulted in higher uptake of these nutrients by the crop. The improved nutrient uptake may be attributed to enhanced nutrient availability, better root development, and sustained nutrient release throughout the crop growth period. Furthermore, the combined application of inorganic fertilizers and organic manure contributed to improved soil fertility, thereby supporting higher biomass production and nutrient use efficiency. In contrast, imbalanced fertilization or sole application of chemical fertilizers resulted in comparatively lower nutrient content and uptake. Therefore, the integration of organic manures with recommended doses of NPK fertilizers emerges as an effective strategy for improving nutrient uptake, maintaining soil health, and sustaining wheat productivity in Vertisol soils under long-term intensive cropping systems.

References

1. Anonymous. Report of United Nations data. United Nations; 2022.
2. Chesti MH, Kohli A, Sharma AK. Effect of integrated nutrient management on yield and nutrient uptake by wheat and soil properties under intermediate zone of Jammu and Kashmir. J Indian Soc Soil Sci. 2013;61(1):1-6.
3. Gomez KA, Gomez AA. Randomized block design. In: Statistical procedures for agricultural research. New York (NY): Wiley Inter Science; 1984. p. 621-635.
4. Goutami N, Rani PP. Integrated nutrient management on content and uptake of nutrients by rice-fallow sorghum. Int J Agric Innov Res. 2016;4(5):928-931.
5. Manjulatha G, Rajanikanth E. Emerging strategies in climate change mitigation and adaptation. Environ Rep Int J. 2022;4(2). doi:10.51470/ER.2022.4.2.06.
6. Jackson ML. Soil chemical analysis. 2nd ed. New Delhi: Prentice Hall of India Pvt Ltd; 1973. p. 69-182.
7. Jat BL, Shaktawat MS, Jat AS. Effects of phosphorus levels alone or in combination with phosphate-solubilizing bacteria and FYM on growth, yield and nutrient uptake of wheat. J Agric Soc Sci. 2007;32:78-82.
8. Kalhapure A, Shete B, Dhonde M, Bokade P. Influence of different organic and inorganic sources of nutrients on maize. Indian J Agron. 2014;59(2):295-300.
9. Katkar RN, Sonune BA, Kadu PR. Long-term effect of fertilization on soil chemical and biological characteristics and productivity under sorghum-wheat system in Vertisol. Indian J Agric Sci. 2011;81(8):58-63.
10. Parvin K. Emerging perspectives on polyphenols and their role in food quality and human health. J Food Biotechnol. 2024;5(1). doi:10.51470/FAB.2024.5.1.30.
11. Khater EA, Ibrahim SB, Awadalla AA. Utilization of some forms of organic wastes for improving soil productivity of newly reclaimed areas at El-Fayoum Governorate, Egypt. Egypt J Soil Sci. 2004;44(3):333-354.
12. Baro J, Vinayaka KS, Chaturvedani AK, Rout S, Sheikh IA, Waghmare GH. Probiotics and prebiotics: The power of beneficial microbes for health and wellness. Microbiol Arch Int J. 2019. doi:10.51470/MA.2019.1.1.1.
13. Kumari R, Kumar S, Kumar R, Das A, Kumari R, Choudhary CD, *et al*. Effect of long-term integrated nutrient management on crop yield, nutrition and soil fertility under rice-wheat system. J Appl Nat Sci. 2017;9(3):1801-1807.
14. Malav JK, Salvi NN, Patel JK, Jat JR, Kumar S, Pavaya RP, *et al*. Nutrient content and uptake by wheat as influenced by Fe and Zn enriched FYM in salt-affected soils of Gujarat. Int J Curr Microbiol Appl Sci. 2019;8(6):2970-2982.
15. Khan MSA, Syed MM, Mohammed MHS. Utilizing artificial intelligence in social media analytics to enhance business performance and understand customer behaviour. J Bus IT Soc Sci. 2022. doi:10.51470/BITS.2022.01.01.09.
16. Syed MM, Khan MSA, Mohammed MHS. Digital leadership in the age of AI: strategies for business growth and innovation. J Bus IT Soc Sci. 2022. doi:10.51470/BITS.2022.01.01.04.
17. Mali DV, Kharche VK, Jadhao SD, Katkar RN, Konde NM, Jadhao SM, *et al*. Effect of long-term fertilization and manuring on soil quality and productivity under sorghum-wheat sequence in Inceptisol. Indian J Agric Sci. 2015;85(5):695-700.
18. Puli M, Katkar RN, Sonune BA. Effect of long-term fertilization on nutrient content and total uptake by crops in Vertisols under sorghum-wheat cropping sequence. Andhra Agric J. 2012;59(3):415-421.

19. Ravankar HN, Naphade KT, Puranik RB, Patel RT. Long-term changes in soil fertility status under sorghum-wheat sequence on Vertisols. In: Swarup A, Reddy DD, Prasad RN, editors. All India Coordinated Research Project on Long-Term Fertilizer Experiments. Bhopal: IISS; 1998. p. 292-297.
20. Sharma KL, Balaguravaiah D, Babu MVS, Rao CS, Mishra PK, Ramesh G, *et al*. Long-term impact of soil and nutrient management practices on soil quality in rainfed Alfisols at Anantapur, Andhra Pradesh. Indian J Dryland Agric Res Dev. 2010;25(1):74-85.
21. Sharma SK, Singh VP, Chouhan N, Sikarwar R. Effect of long-term fertility management practices on soil and crop productivity of soybean grown in Vertisols of western Madhya Pradesh. Int J Agric Sci. 2016;8(60):3371-3377.
22. Thakur R, Sawarkar SD. Influence of long-term continuous application of nutrient inputs on spatial changes of soil physico-chemical properties of medium black soil. J Soils Crops. 2009;19(1):14-20.
23. Tolba MH, Baddour GA, El-Ghamry AM. Effect of different sources of organic manures on eggplant and some soil properties. J Agric Sci Mansoura Univ. 2003;18(Special Issue):127-135.
24. Mohammed MHS, Khan MSA, Syed MM. Remote work culture: the impact of digital transformation on workforce productivity. J e-Sci Lett. 2023;4(1). doi:10.51470/eSL.2023.4.1.01.
25. Mohammed MHS, Khan MSA, Syed MM. Green business strategies: sustainable technologies and digital transformation. J e-Sci Lett. 2023;4(1). doi:10.51470/eSL.2023.4.1.0.
26. Mohammed MHS, Syed MM, Khan MSA. Cryptocurrency and global markets: exploring risks, regulations and strategies for business integration. J Bus IT Soc Sci. 2022. doi:10.51470/BITS.2022.01.02.01.
27. Venugopal G, Sharma SHK, Qureshi AA, Vidyasagar GEC. Inorganic fractions of nitrogen and phosphorus in soils and nitrogen and phosphorus uptake by sorghum under long-term fertilization and manuring. Res J Agric Sci. 2017;8(5):1122-1126.
28. Wang JY, Yan XY, Gong W. Effect of long-term fertilization on soil productivity in the North China Plain. Pedosphere. 2015;25(3):450-458.