Impacts of long-term application of fertilizer and manures on physico-chemical properties, phosphorus uptake and crop yield at different growth stages of wheat

Abstract

A study was conducted during 2018-19 from All India Coordinated Research Project on Long Term Fertilizer Experiment initially started in 1971,at the research farm of Division of Soil Science and Agricultural Chemistry, Indian Agriculture Research Institute, New Delhi, to study the effect of long termintegrated application of fertilizers and manures on physico-chemical properties of soil and phosphorus availability in maize-wheat cropping sequence.The treatments were T_1: Control, T_2: 100%N, T_3: 100%NP, T_4: 100%NPK, T_5: 150% NPK, T_6: 100%NPK+5t FYM and T_7: 100% NPK+ Zn-5 $kgha^{-1}$. The results revealed that the physico-chemical properties like pH and electrical conductivity recorded highest under control and lowest recorded under 100% NPK+FYM. Available phosphorus content at all four stages of wheat was significantly greater under NPK+FYM followed by 150% NPK treatment and lowest under nitrogen alone (100% N) and unfertilized treatment (control).Initially available phosphorus in soil ~~was~~ ranged from 13.5 to 39.8 and 15.4 to 37.9 kg ha^{-1} at 0-15cm and 15-30cm depth, respectively. At ~~tillering stage available~~ the tillering stage, P was 20.7 to 43.7 and 16.5 to 38.1 $kgha^{-1}$ at 0-15cm and 15-30cm depth,respectively. ~~At panicle emergence stage it~~ The panicle emergence stage was 24.1 to 48.4kg ha^{-1} and 18.6 to 42.3 at 0-15cm and 15-30cm depth. At harvest of wheat crop available, P ranged from 20.5 to 41.8 and 16.5 to 39.1 kg ha^{-1} at0-15cm and 15-30cm depth, respectively. Total phosphorus uptake and crop yield significantly increased under 150% NPK treatment, followed by 100% NPK+FYM.

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Keywords: Available phosphorus, farmyard manure, pH, electrical conductivity, total phosphorus uptake

Introduction:

Wheat (*Triticumaestivum*) is the most extensively grown cereal crop ~~in the world, covering about 237 million hectare annually, accounting for a total of 420 million tonnes (Ramadas et al.2020),~~globally, covering about 237 million hectares annually, accounting for a total of 420 million tonnes (Ramadas et al.2020) which requiresa higher amount of chemical fertilizers for production. It is observed that continuous use of inorganic fertilizers leads to deterioration in soil chemical, physical, and biological propertiesand soil health (Mahajan et al.~~,~~ 2008). The negative impacts of chemical fertilizers, coupled with escalating prices, have led to growing interest~~s~~ in ~~the use of~~ using organic fertilizers as a source of nutrients (Satyanarayana et al.~~,~~ 2002). FYM supplies all major nutrients (N, P, K, Ca, Mg, S~~,~~) necessary for plant growth~~, as well as~~ and micronutrients (Fe, Mn, Cu and Zn). Hence, it acts as a mixed fertilizer (Dejene and Lamlam, 2012). FYM improves soil physical, chemical and biological properties. Improvement in the soil structure due to FYM application leads to a better environment for root development (Prasad et al.~~,~~ 2000). The use of FYM alone as a substitute ~~to~~ forinorganic fertilizer is not~~ be enough to maintain the present levels of crop productivity~~ enough to maintain the present crop productivity levels of high yielding varieties (Efthimiadou et al. 2010). Long-term experiments allow ~~not only monitoring changes in crop yields and nutrient balances with time but also~~ monitoring changes in crop yields and nutrient balances with time and studying the impact of different nutrient management scenarios on the sustainability of wheat-based systems (Kumari et al. 2017). Therefore, integrated nutrient management in which both organic manures and inorganic fertilizers are used simultaneously is the most effective method to maintain ~~a~~ healthy and sustainably productive soil. Emerging evidence indicated that integrated soil fertility management involving the judicious use of combined organic and inorganic resources is ~~a feasible approach~~ feasible to overcome soil fertility constraints. With ~~these~~ thisbackground, the present study was conducted to study the effect of long-term application of fertilizers and manures on physico-chemical properties of soil and phosphorus availability.

Material and methods

Experimental Site and Treatment Details

The present investigation was carried out during 2018-19 from an ongoing long-term fertilizer experiment which was initiated in 1971 with maize-wheat cropping sequence, research farm of the Division of Soil Science and Agricultural Chemistry, ICAR-Indian Agricultural Research Institute, New Delhi (28^0 37'- 28^0 39' N latitude, 77^0 9'- 77^0 11' longitude and 250m above mean sea level). The site is situated in the Upper Gangetic Plain transect of the Indo- Gangetic Plain (IGP) region. It ~~have~~hasa hot semi-arid climate with a mean annual rainfall of 650mm, mean minimum temperature 17^0C and mean maximum annual temperature of 31^0C. ~~At the study site, the soil is alluvial in origin,~~ The soil is alluvial in origin at the study site;the texture is sandy loam (*TypicHaplustept*), non-saline and slightly alkaline in reaction.

The experiment was designed with ~~7~~ sevendifferent treatments,replicated thrice in a randomized complete block design. Three blocks were separated with ~~the~~ agap of 2.0m,

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whereas individual plots (21m x8m) were separated with a distance of 1.0m. The pooled soil sample ~~were~~ wasanalysed for different soil characteristics of the surface and sub-surface soil (0-15cm and 15-30cm) of the experiment at different stages of wheat. The treatments consist of T_1: Control, T_2: 100%N, T_3: 100%NP, T_4: 100%NPK, T_5: 150% NPK, T_6: 100%NPK+5t FYM and T_7: 100% NPK+ Zn- 5 $kgha^{-1}$. The soil of the experimental field has 8.3 pH, 0.45 dSm^{-1} electrical conductivity, 10.6 cmol (p^+) kg^{-1} cation exchange capacity (CEC), 0.44 % organic carbon, 94 mg kg^{-1}available N, 7.14 mg kg^{-1}available P and 69 mg kg^{-1}available K. The recommended dose of fertilizers for wheat was 120:60:40 NPK $kgha^{-1}$. In addition ~~treatment, uniform dose of Zn was applied as zinc sulphate at 5 $kgha^{-1}$ just before sowing of *rabi* crop, whereas~~, uniform dose ofo treatment, uniform Zn, was applied as zinc sulphate at five kgha-1 just before sowing of rabi crop. In contrast,FYM was applied as a source of organic manure at 5 t ha^{-1}just before ~~sowing of *kharif*~~*Kharif*crop in the respective treatments.

Soil Sampling and Analyses

Using a tube auger, soil samples were collected from two different depths (0–15 and 15–30 cm) from each plot~~s~~. All soil samples were ~~air~~ air-dried under shade, ground to pass through 70-mesh (0.27-mm) sieve, processed, and stored for chemical analysis. Soil pH was determined using 1:2 soil/water suspension, electrical conductivity was determined by using a conductivity bridge meter (Jackson, 1973).

Olsen P was determined by shaking the soil with 0.5 M sodium bicarbonate ($NaHCO_3$) (pH 8.5) for 30 min, followed by photometrical measurement using the molybdate– ascorbic acid method (Olsen and Sommers, 1982).

Statistical Analysis

Data were analyzed statistically using randomized block design (RBD) analysis of variance (ANOVA),and these were computed ~~by~~ using the SAS program.(SAS version 9.3; Cary NC) (Gomez and Gomez 1984).

Results and Discussion:

The application of fertilizers and manures showed a positive response ~~on~~ tosoil physico-chemical properties. The perusal of the data on soil reaction of the experimental soil at different stages of wheat indicated that intensive cropping with continuous use of fertilizer alone or in combination resulted in~~a~~ slight change~~s~~ in soil pH (table 1). In the present investigation pH of soil varied from 7.96 to 8.16 at 0-15cm and 7.85 to 8.14 at 15-30cm atthe initial stage of wheat, at tillering stage pH of the soil was 7.64 to 7.85 at 0-15cm and 7.51 to 7.80 at 15-30cm, 8.01 to 8.20 at 0-15 cm and 7.79 to 8.06 at 15-30 cm in panicle emergence stage and ~~at~~ harvest stage soil pH ranged from 8.02 to 8.24 at 0-15cm and 7.93 to 8.16 at 15-

30cm. ~~at~~ At all four stages of wheat pH under control treatment significantly greater than other treatment, lowest valve observed in NPK+FYM treatment at both the depths, no appreciable change in soil pH ~~with respect to~~ concerning depth as a result of long term fertilization and manuring. ~~Soil pH in all treatments after 48th years of cropping and fertilization had a trend of reduction as~~ After 48th years of cropping and fertilization, soil pH in all treatments had a trend of reduction compared with the initial value. In addition, soil pH values in the non-balanced fertilization treatments were higher than those of the balanced fertilization. This result ~~was in contrast~~, in contrast, contrasts with Devi (2002) reported that there was no significant effect on soil pH within 13 years of cropping on a VerticHaplaquept. Dwivediet al. (2007) reported that continuous cropping and fertilizer use has no adverse effect on ~~the pH of soil~~soil pH and might be due to the high buffering capacity of the soil. These results are also in agreement with Yaduvanshiet al. (2013~~);~~), Santhyet al. (2001); Singh et al. (2002). There was no appreciable change in pH of the soil with respect to depth ~~as a result of~~ due to continuous fertilizer additions and intensive cropping over 48th years.The EC measured also did not show any appreciable changes over the different stages of wheat due to continuous fertilizers application in almost all the treated plots presented in table 2.Sharma (1992) ha~~ve also reported that black soils that possessed inherent high buffering capacity which~~s also reported that black soils that possessed inherent high buffering capacity affected the slight alterations in EC of soil due to fertilizer addition. There were no considerable changes in ~~EC of the soil with depth as a result of~~ the soil's EC with depth due to continuous fertilizer addition over the 36th years. These results are also in agreement with the finding of Tomar (2003).

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Treatments	Initial	Tillering	Panicle	Harvest
Surface soil (0-15cm)				

Table 1

Effect of long -term nutrient management options on soil pH at different stages of wheat at 0-15cm and 15-30cm depth

T1	8.16	7.85	8.20	8.24
T2	8.09	7.83	8.16	8.19
T3	8.08	7.76	8.11	8.15
T4	8.06	7.75	8.09	8.12
T5	8.03	7.68	8.06	8.08
T6	7.96	7.64	8.01	8.02
T7	8.16	7.80	8.16	8.21
SE(±)	1.28	0.88	0.66	1.06
LSD (P=0.05)	NS	NS	NS	NS
Sub-surface soil (15-30cm)				
T1	8.14	7.80	8.06	8.16
T2	8.11	7.70	8.00	8.12
T3	8.01	7.72	7.96	8.07
T4	7.99	7.66	7.93	8.05
T5	7.91	7.59	7.81	8.03
T6	7.83	7.51	7.79	7.93
T7	8.11	7.72	8.00	8.12
SE(±)	1.22	0.55	0.56	0.60
LSD (P=0.05)	NS	NS	NS	NS

	Initial	**Tillering**	**Panicle**	**Harvest**
Surface soil (0-15cm)				
T1	0.33	0.36	0.35	0.34
T2	0.31	0.33	0.33	0.32
T3	0.33	0.36	0.35	0.34
T4	0.30	0.32	0.29	0.30
T5	0.31	0.33	0.33	0.32
T6	0.30	0.33	0.30	0.31

Table 2

Effect of long- term nutrient management options on EC (dSm^{-1}) of the soil at different stages of wheat at 0-15cm and 15-30cm depth

T7	0.31	0.33	0.33	0.32
SE(±)	0.01	0.06	0.04	0.05
LSD (P=0.05)	NS	NS	NS	NS
Sub-surface soil (15-30cm)				
T1	0.31	0.34	0.31	0.33
T2	0.30	0.32	0.30	0.32
T3	0.29	0.34	0.31	0.31
T4	0.29	0.30	0.28	0.31
T5	0.30	0.33	0.30	0.32
T6	0.28	0.31	0.29	0.30
T7	0.30	0.33	0.30	0.32
SE(±)	0.06	0.01	0.01	0.01
LSD (P=0.05)	NS	NS	NS	NS

Available P content in soil vary with cropping period, phosphorus availability in soil at initial stage (13.5 to 39.8 kg ha^{-1}) at 0-15cm depth, (15.4 to 37.9 kg ha^{-1}) at 15-30 cm depth, at tillering stage (20.7 to 43.7 kg ha^{-1}) at 0-15 cm and (16.5 to 38.1 kg ha^{-1}) at 15-30 cm depth, at panicleemergence stage (24.1 to 48.4 kg ha^{-1}) at 0-15 cm depth and (18.6 to 42.3kg ha^{-1}) at 15-30 cm depth. At harvest stage of wheat crop available P ranged from (20.5 to 41.8 kg ha^{-1}) at 0-15 cm depth and (16.5 to 39.1 kg ha^{-1}) at 15-30 cm depth, respectively (table 3). With the increasing maturity of the crop, P availability increases in soil due to lesser fixation of phosphorus ~~in soil~~. The result from ~~this~~ theselong-term experiments indicate that at all four stages of wheat, imbalanced use of fertilizer has reduced the available P content in the soils, a significant reduction in available P content observed under nitrogen alone (100% N), and unfertilized treatment occurred due to removal of P by the crops in the absence of P supplementation through external source. Available P significantly greater under NPK+FYM followed by 150% NPK treatment at both the depths, respectively. Khiari~~,~~ (2005) also found that the available phosphorus varied widely from 5.85 kg ha^{-1} in control to 52.57 kg ha^{-1} in 100%NPK+Lime+FYM treated plot. ~~Addition~~ The addition of FYM to 100%NPK measured the next best value for Olsen P. Higher amount of available P measured in FYM amended treatment is due to the addition of FYM, reduced or no fixation by Al/Fe with the increase in pH, more solubility of inorganically bound P and mineralization of organic P. Garg and Aulukh (2010) ~~have~~ had also reported that the highest content was found when the integrated application of fertilizer was practised with FYM (39.83 kg ha^{-1}) followed by 150% NPK (39.55 kg ha^{-1}) treatments indicating the beneficial effect of FYM on mineralization of P to a greater extent in soil.

Treatments	Initial	Tillering	Panicle	Harvest

Thamaraiselviet al. (2012) reported that increases in available phosphorus due to FYM application. Similarly, Aziz et al. (2010) reported maximum soil N and P contents after a maize harvest for FYM. In contrast, ~~whereas~~ the minimum N and P contents were found for the treatments with the application of inorganic NPK fertilizer. Available P content of the soil increased by appl~~ication of~~ying inorganic P fertilizer, green manure and FYM treatments. Increased available N and P by combined use of inorganic and organic fertilizers were also reported by Thind et al. (2007).

Table 3

Effect of long-term nutrient management options on available-P (kg ha^{-1}) at different stage of wheat at 0-15cm and 15-30cm depth

Surface soil (0-15cm)				
T1	13.5	20.7	24.1	20.5
T2	16.9	15.0	18.5	15.3
T3	33.3	36.2	36.7	34.7
T4	36.0	39.2	39.5	36.6
T5	38.4	43.4	45.9	41.0
T6	39.8	43.7	48.4	41.8
T7	32.8	33.8	36.2	33.0
SE(±)	3.84	2.95	2.06	3.57
LSD (P=0.05)	7.84	6.23	4.54	7.34
Sub-surface soil (15-30cm)				
T1	15.4	16.5	18.6	16.5
T2	11.8	13.6	15.1	12.2
T3	32.2	32.6	32.4	34.9
T4	34.1	35.7	36.4	36.4
T5	37.7	37.7	41.5	38.4
T6	37.9	38.1	42.3	39.1
T7	30.4	30.9	30.8	32.1
SE(±)	2.29	2.40	2.09	2.43
LSD (P=0.05)	5.02	5.23	4.55	5.29

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Crop Yield:

The data on grain yield of wheat presented in table 4 revealed that the highest grain yield5.74 t ha^{-1} was obtained due to continuous application of 150% NPK, which was statistically on par with 100% NPK + FYM (5.46 t ha^{-1}), 100% NPK (5.12 t ha^{-1}) and NPK +Zn (5.06 t ha^{-1}). Among the treatments, the lowest grain yield of 1.93 t ha^{-1} was recorded inthe control. Continuous application of only 100% N every tear resulted in reduced yield compared to 100% NP (4.66 t ha^{-1}) and NPK (5.12 t ha^{-1}), emphasizing the need ~~of~~ forbalanced fertilization. Application of 150% NPK and 100% NPK +FYM treated plots recorded higher yields (grain and straw) as compared to all other treatments, which could be due to higher nutrient uptake and improvement of soil environment (Humneet al. 2008), and FYM proved to be beneficial in enhancing crop productivity and soil fertility (Khambalkaret al.2012) due to the indirect effect resulting from reduced loss of organically supplied nutrients.

Total phosphorus uptake:

It is evident from table 4 that the continuous application of 150% NPK had a significant positive impact on the uptake of nutrients over other treatments. The highest phosphorus uptake by wheat was observed in T_5 treatment (24.3 kgha^{-1}). While~~,~~ the lowest phosphorus uptake was found in treatment T_1 (15.5 kg ha^{-1}). Increasing P levels significantly increased total P uptake by wheat. The increase of 4.9 and 6.5 kg ha^{-1} P uptake was observed with ~~the application of~~ 60 and 120 kg P_2O_5 ha^{-1}phosphatic fertilizers, respectively, over control. These results ~~are in conformity~~ conform with the results obtained by Setia and Sharma (2007).

Table 4:

Effect of long-term nutrient management options on total phosphorus uptake and crop yield of wheat

Treatments	Crop Yield (t ha^{-1})			Total P Uptake (kg ha^{-1})		
	Grain	Straw	Total	Grain	Straw	Total
Control	1.93	3.26	5.19	13.2	2.23	15.5
N	4.60	5.32	9.92	13.5	3.35	16.9
NP	4.66	6.54	11.2	13.9	3.49	17.3
NPK	5.12	6.94	12.0	17.9	4.31	22.2
150%NPK	5.74	7.95	13.6	19.1	5.16	24.3
NPK+ FYM	5.46	7.68	13.1	18.0	4.36	22.3
NPK+Zn	5.06	7.41	12.4	16.2	4.20	20.4
SE(±)	0.25	0.16	0.41	0.93	0.38	1.31
LSD (P=0.05)	0.71	0.55	1.26	2.03	0.82	2.85

Conclusions:

This study has shown that the long-term application of fertilizers and manures on physico-chemical properties of soil and phosphorus availability. At all four stages of wheat, pH under control treatment greater than other treatment, lowest value observed in NPK+FYM treatment. Electrical conductivity did not show any appreciable changes over the different stages of wheat due to continuous fertilizers application. Available P content in soil ~~vary~~ varieswith the cropping period. Available phosphorus content at all four stages of wheat was significantly greater under NPK+FYM followed by 150% NPK treatment, lowest under nitrogen alone (100% N) and unfertilized treatment occurred due to removal of P by the crops in the absence of P supplementation through external sources at both surface and sub-surface soil layers. Crop yield and total phosphorus uptake can only be achieved by supplementing 150% NPK treatments.

Comment [ML(7]: Again long winding sentence, difficult to follow.

References:

Azeez, J. O., and Van Averbeke, W. 2010. Fate of manure phosphorus in a weathered sandy clay loam soil amended with three animal manures. *Bio resource technology* 101(16): 6584-6588.

Dejene, M. and M. Lemlem 2012. Integrated agronomic crop managements to improve tef productivity under terminal drought. *Water stress. Vienna: In Tech* 235-254.

Devi, S. 2002. Effect of long term manuring on soil quality of a VerticHaplaquept under rainfed rice production system (doctoral dissertation, Orissa univesrity of agriculture and technology; Bhubaneswar).

Dwivedi, A.K., M. Singh, D.L. Kauraw, R.H. Wanjari and S.S. Chauhan 2007. Research bulletin on impact of fertilizer and manure use for three decades on crop productivity and sustainability and soil quality under Soybean-Wheat system on a Vertisol in central India. IISS (ICAR), Bhopal.

Efthimiadou, A., D. Bilalis, A. Karkanis and B. Froud Williams 2010. Combined organic/inorganic fertilization enhances soil quality and increased yield, photosynthesis and sustainability of sweet maize crop. *Australian Journal of Crop Science* 4(9): 722-729.

Garg, A. K., andAulakh, M. S. 2010. Effect of long-term fertilizer management and crop rotations on accumulation and downward movement of phosphorus in semi-arid subtropical irrigated soils. *Communications in soil science and plant analysis* 41(7): 848-864.

Gomez, K. A., and Gomez, A. A. 1984. *Statistical procedures for agricultural research*. John Wiley & Sons.

Humne, L., Bajpai, R. K., Kumar, D., and Jangre, A. 2008. Influence of long–term fertilizer application changes in available nutrients status and yield of wheat. *Journal of Soils and Crops*, **18**(2): 301-304.

Jackson, M. L. 1973. Soil Chemical Analysis, Wisconsin Prentice Hall of India Pvt. *Ltd., New Delhi*, **46:**
128.

Kumari, R., Kumar, S., Kumar, R., Das, A.,Kumari, R., Choudhary, C. D., and Sharma, R. P. 2017. Effect of long-term integrated nutrient management on crop yield, nutrition and soil fertility under rice-wheat system. *Journal of Applied and Natural Science*, **9**(3):1801-1807.

Khambalkar, A.P., Tomar, P.S and Verma, S.K. 2012. Long –term effects of integrated nutrient management on productivity and soil fertility in pearl millet (Pennisitumglaucum) – mustard (Brassica juncea) cropping sequence. *Indian Journal of Agronomy*, **57** (3): 222 -228.

Khiari, L., and Parent, L. E. 2005. Phosphorus transformations in acid light-textured soils treated with dry swine manure. *Canadian Journal of Soil Science85*(1): 75-87.

Mahajan, A. N. I. L., Bhagat, R. M., and Gupta, R. D. 2008. Integrated nutrient management in sustainable rice-wheat cropping system for food security in India. *SAARC Journal of Agriculture 6*(2): 29-32.

Olsen, S.R. and Sommers, L.E. 1982.Phosphorus. Methods of Soil Analysis Part 2 Chemical and Microbiological Properties, *American Society of Agronomy, Soil Science Society of America,* 403-430.

Prasad, B., and Sinha, S. K. 2000. Long-Term Effects of Fertil-izers and Organic Manures on Crop Yields, Nutrient Balance, and Soil Properties in Rice-Wheat Cropping System in Bihar. *Long-Term Soil Fertility Experiments in Rice-Wheat Cropping Systems. Rice-Wheat Consortium Paper Series6*: 105-119.

Ramadas, S., Kumar, T. K., and Singh, G. P. 2020. Wheat production in India: Trends and prospects. *Recent Advance in Grain Crop Research* 1-17.

Santhy, P., Muthuvel, P., and Selvi, D. 2001. Status and impact of organic matter fractions on yield, uptake and available nutrients in a long-term fertilizer experiment. *Journal of the Indian Society of Soil Science* 49(2): 281-285.

Sharma, P. K., and Tripathi, B. R. 1992. Fractions of phosphorus from some acid hill soils of north-west India. *Journal of the Indian Society of Soil Science*40(1): 59-65.

Satyanarayana, V., Vara Prasad, P. V., Murthy, V. R. K., and Boote, K. J. 2002. Influence of integrated use of farmyard manure and inorganic fertilizers on yield and yield components of irrigated lowland rice. *Journal of plant nutrition* 25(10): 2081-2090.

Singh, R. 2002. Imapact of continuous application of nutrients on soil physical environment and nutrient status (Doctoral dissertation, JNKVV, Jabalpur).

Setia, R. K., and Sharma, K. N. 2007. Dynamics of forms of inorganic phosphorus during wheat growth in a continuous maize-wheat cropping system. *Journal of the Indian Society of Soil Science*, **55**(2): 139-146.

Yaduvanshi, N. P. S., Sharma, D. R., andSwarup, A. 2013. Impact of integrated nutrient management on soil properties and yield of rice and wheat in a long-term experiment on a reclaimed sodic soil. *Journal of the Indian Society of Soil Science*61(3): 188-194.

Thamaraiselvi, T., Brindha, S., Kaviyarasi, N. S., Annadurai, B., and Gangwar, S. K. 2012. Effect of organic amendments on the bio chemical transformations under different soil conditions. *International Journal of Advanced Biological Research*, 2 (1):171-173.

Thind, S. S., Sidhu, A. S., Sekhon, N. K., and Hira, G. S. 2007. Integrated nutrient management for sustainable crop production in potato-sunflower sequence. *Journal of Sustainable Agriculture* 29(4): 173-188

Tomar, V. K. 2003. Spatial distribution of inorganic and organic content of P and S as influenced by long term application of fertilizers and manure in TypicHaplustert (Doctoral dissertation, M. Sc. Thesis).