Establishment of soil fertility gradient and its statistical verification based on soil and crop response

ABSTRACT

In order to assess the effects of soil fertility gradient on crop yield, nutrient uptake, and soil fertility, a field experiment was conducted on an oat crop at the Norman. E. Borlaug Crop Resea.rch Centre, G.B.U.A. &T, Pantnagar, Uttarkhand, India during *rabi* 2020–21. The experiment field was divided into three equal strips, and three grades of fertilizer N, P_2O_5, and K_2O were applied in strip I, strip II, and strip III, respectively, as $N_0P_0K_0$, $N_{100}P_{100}K_{100}$, and $N_{200}P_{200}K_{200}$. As a source of nutrients, N:P:K mixture, urea, single super phosphate and muriate of potash were used. Exhaust crop oat was cultivated using the recommended agronomic practices and harvested at maturity. From each strip, samples of grain and straw were taken, their nitrogen, phosphorus, and potassium contents were evaluated, and total nutrient uptake was calculated.A short-term exhaust crop is grown in order to transform fertilizer in the soil with plant and microbial activities.

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Keywords: Soil fertility gradient, oat, STCR, nitrogen, phosphorus, potassium, nutrient uptake, yield and Mollisol

1. INTRODUCTION

Nutrient management refers to practices to ensure crops receive the necessary amounts of essential nutrients for optimal growth and development. Nutrient application and management practices in various ecologies and production systems are critical for increasing farm productivity, resource efficiency, food grain production, and reducing environmental risks. Fertilizer is a major cost in crop production and using the right amount of fertilizer is crucial for both economic efficiency and environmental sustainability. Over-fertilization can lead to waste of resources and negative environmental impacts, while under-fertilization can result in lower crop yields and poor quality. Therefore, it's important to follow recommended guidelines and use soil tests to determine the appropriate amount and type of fertilizer needed. Fertilizer consumption in India has increased remarkably over the last few decades. However, it is important to note that Indian agriculture currently has a 'net negative nutrient balance' of 8-10 million tonnes per year [1], which is expected to increase to around 15 million tonnes by 2025. Overuse of chemical fertilizers hardens the soil, reduces soil fertility, pollutes air, water, posing environmental risks and sole use of chemical fertilizers resulted in low microbial activity in the cropping system [2]. Soil test provides the requisite information about the amounts of nutrients available in the soil and their imbalances, while fertilizer recommendations aim at correcting the imbalances in nutrients according to crop requirements [3]. Nitrogen, phosphorus, and potassium depletion are primarily caused by intensive crops and imbalanced fertilizer applications. Soil test crop response (STCR) approach takes into account, the amount of the nutrient removed by the crop, initial level of soil fertility, the efficiency of nutrient uptake from the soil and fertilizers; therefore, fertilizer prescription based on this approach is designed to maintain soil fertility and reduce fluctuations in yield.

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Soil fertility gradient experiment involves the study of changes in soil fertility levels along a gradient. This is often achieved by creating transects, plots or stripes of soil at different distances from a point of reference, such as a stream or a fertilizer application site, and measuring soil properties such as available nutrients like N, P and K. The approach aims to eliminate the influence of other factors affecting yield, such as crop, climate, and management, by selecting one field over which extensive treatments are superimposed to obtain crop responses for correlating with soil test values artificially created by differential fertilizer treatments prior to conducting the regular experiment, and it provides a scientific basis for balanced fertilization between applied and soil available forms of nutrients.. It is evident that STCR based approach of nutrient application has definite advantage in terms of increasing nutrient response ratio over general recommended dose of nutrient application [3].

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In India, notably in the northern, western, and central states, oat (*Avena sativa* L.) is an important winter cereal fodder crop with wide adaptability. The crop occupies maximum area in Uttar Pradesh (34%), followed by Punjab (20%), Bihar (16%), Haryana (9%) and rest of the area is shared by Gujrat, Orissa, Uttarakhandetc. As of May 2021, oat is seventh in world cereal production [4]. Oat is suitable for human consumption as oatmeal and rolled oats, one of the common uses is as livestock feed. Oat grows best in loam and clay loam soil with adequate drainage. Due to their high nutrient responsiveness, oat is one of the nutrient exhaustive crops that are useful in establishing artificial soil fertility gradient.

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In fertilizer gradient experiment, exhaust crop is cultivated in such a way that the fertilizers undergo soil transformations due to plant and microbial activities. Nutrients such as nitrogen, phosphorus, and potassium are essential in high quantities as they play a role in plant growth and development. The goal of this study was to evaluate the effect of soil fertility gradients on yield, nutrient uptake, and soil fertility.

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2. MATERIAL AND METHODS

The methodology used in this study was to achieve as much variation in soil fertility levels as possible in the same field, so that the precise correlation between yield and soil fertility level may be evaluated without interference from other factors affecting yield [5]. The operational range of variation in soil fertility was artificially created to generate data covering an appropriate range of values for each controllable variable (fertilizer dose) at different levels of an uncontrollable variable (soil fertility) that may not normally be expected at one place.

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Therefore, a field experiment employing exhaust crop oat (var. UPO 94) was carried out during rabi 2020–21 at the Norman E. Borlaug Crop Research Centre, G.B. Pant University of Agriculture and Technology, Pantnagar (29^0 N latitude, 79^0 29' E longitude, and 243.84 m above MSL), District U.S. Nagar, Uttarakhand, in order to create soil fertility variation in the same field and to evaluate the impact of soil fertility gradient experiment on crop yield, nutrient uptake and soil fertility. Initial soil samples were taken before fertilizers were applied, and the experimental field was divided into three equal strips (47 m x 7.5 m). Strips I, II, and III each received a different quantity of the fertilizer nutrients N, P2O5, and K2O ($N_0P_0K_0$, $N_{100}P_{100}K_{100}$, and $N_{200}P_{200}K_{200}$) (Table1). The N: P: K mixture, urea, single super phosphate and MOP fertilizers were employed as nutrient sources. Exhaust crop oat was produced using the recommended agronomic techniques, and when the crop reached 50 % flowering stage, a sample sized 4 m^2 (2 m x 2 m) area from randomly selected three spots from each strip was harvested.

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Soil samples were obtained from the surface layer prior to the sowing of the exhaust crop, air dried in shade, processed, and used in chemical analysis for EC[6], soil pH [7], soil organic carbon [8], available nitrogen by alkaline $KMnO_4$ method [9], available phosphorus by Olsen's method [10] and available potassium by neutral normal ammonium acetate [11]. After the harvesting, twenty-four soil samples were taken from each strip and analyzed using the same methods as above to determine the mineralizable nitrogen, extractable phosphorus, and exchangeable potassium.

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3. RESULTS AND DISCUSSION

3.1 Initial soil properties

The soil of the experimental field was sandy loam in texture, with pH 6.91, electrical conductivity 0.32 dSm^{-1} and soil organic carbon 0.61 percent. Initial soil test value of available nitrogen, available phosphorus and available potassium was 163.07 kg N ha^{-1}, 16.43 kg P ha^{-1} and 150.66 kg K ha^{-1}, respectively.

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Table 1. Nutrient doses applied in soil fertility gradient experiment with oat crop

Strip	Symbol	Nutrient dose (kg ha^{-1})		
		N	P_2O_5	K_2O
I	N0P0K0	0	0	0
II	N1P1K1	100	100	100
III	N2P2K2	200	200	200

3.2 Yield and nutrient uptake by exhaust crop oat

Results showed that application of graded level of nutrients (N, P_2O_5 and K_2O) on yield and uptake of exhaust crop oat was significant (Table 2). According to the results of the soil fertility gradient experiment, strip III (181.11 q ha^{-1}) obtained the maximum dry matter yield of the exhaust crop, followed by strip II (162.94 q ha^{-1}) and strip I (which produced the least amount) (138.73 q ha^{-1}). In strips I, II, and III, the yield of green forage was 350.25 q ha^{-1}, 422.48 q ha^{-1}, and 452.57 q ha^{-1}, respectively. In strip III, where the fertilizer N, P_2O_5 and K_2O applied were twice as that of strip II, the green forage yield recorded an increase of 29.21 and 7.12 percent over strip I and II respectively. Whereas dry matter yield recorded an increase of 30.54 and 11.15 percent over strip I and II respectively. This is likely that the graded levels of nutrient application improved nutrient uptake and growth parameters. Choudhury[12] observed that applying graded fertilizers to a gradient crop of sorghum resulted in increased grain and straw yield.

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Table 2. Effect of graded levels of nutrients on grain yield, straw yield and nutrient uptake by oat in soil fertility gradient experiment

Strip	Green forage yield	Dry matter yield	Total nutrient uptake (kg ha^{-1})		
	q ha^{-1}		N	P	K
I	350.25	138.73	306.59	18.03	283.01
II	422.48	162.94	413.87	29.33	376.39
III	452.57	181.11	492.62	41.66	469.07

Total nitrogen uptake by the crop was recorded in order of 306.59 kg ha^{-1} in strip I, 413.87 kg ha^{-1} in strip II and 29.33 kg ha^{-1} in strip III. Percent increase in nitrogen uptake in strip III over strip II and strip I was 60.67 and 19.02, respectively. Total phosphorus uptake by crop was recorded maximum 18.03 kg ha^{-1} under strip III followed by 29.33 kg ha^{-1} in strip II and minimum 41.66 kg ha^{-1} in strip I. Percent increase in phosphorus uptake in strip III over strip II and strip I was 131.05 and 42.03, respectively. Total uptake of potassium by crop was maximum 283.01 kg ha^{-1} in strip III followed by 376.39 kg ha^{-1} in strip II and the least 469.07 kg ha^{-1} in strip I. The percent increase in uptake of in strip III over strip II and strip I was 65.74 and 24.62, respectively (Table 2). Higher levels of phosphorus application would have resulted in more root proliferation of the crop, were the cause of the increased phosphorus uptake [13].

Since crop yield and total nutrient uptake by the exhaust crop followed the same trend as the applied fertilizer nutrients, i.e. strip III > strip II > strip I, yield and uptake data suggested that a fertility gradient had been developed. This could be attributed to the graded amounts of N, P, and K that were applied in strips and had an impact on grain yield, nutrient availability, and crop nutrient uptake. Similar findings observed by Srinivasan and Angayarkanni [14].

3.3 Soil fertility status after the harvest of exhaust crop

Strip wise average soil test values after the harvest of exhaust crop showed effect of varied levels of nutrient treatments on soil properties (Table 3). Soil available nitrogen, phosphorus and potassium content prominently increased from strip I to strip III. Average soil test value of alkaline $KMnO_4$-N was 163.07 kg N ha^{-1} in strip I, 188.16 kg N ha^{-1} in strip II and 200.70 kg N ha^{-1} in strip III. Mean value of available soil phosphorus was 16.43 kg P ha^{-1} in strip I, 18.18 kg P ha^{-1} in strip II and 20.17 kg P ha^{-1} in strip III. Average soil test value of available potassium was 156.57, 162.73 and 167.32 kg K ha^{-1} in strip I, II and III, respectively. Soil test values of alkaline KMnO4-N, Olsen's-P and NH4OAc-K was highest in strip III followed by strip II and the least in strip I. Marked increase in fertility gradient build up with respect to available N, P and K was noted from strip I to strip III (strip I< strip II< strip III). Highest soil test values of available nutrients in strip III might be due to very high nutrient application with super-optimal doses of nutrients in strip III than no application of nutrients in strip I. Such types of marked fertility gradient build up by preliminary fertility gradient experiment have been also reported by Singh *et al*. [15].

Table 3. Effect of graded levels of nutrients on soil fertility status after the harvest of exhaust crop in soil fertility gradient experiment

Strip	Symbol	Nutrient (kg ha^{-1})		
		Available nitrogen	Available phosphorus	Available potassium
I	N0P0K0	163.07	16.43	156.57
II	N1P1K1	188.16	18.18	162.73
III	N2P2K2	200.70	20.17	167.32

3.4 Statistical verification of proper creation of fertility gradient

Analysis of variance was carried out by using the available soil nutrients (Alkaline $KMnO_4$-N, Olsen's-P and NH_4OAc-K) separately as dependent variables (Table 4). It was observed that with available soil nitrogen (SN), available soil phosphorus (SP) and available soil potassium (SK) as dependent variable separately, effect of the strip was highly significant.

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Table 4. Significance, 'R' square, CV(%) and mean of soil test values of whole plots

Dependent variable	P level	R square	Average	SD	CV (%)
SN	<0.01**	0.765	188.97	19.16	10.41
SP	<0.01**	0.803	18.26	1.87	10.24
SK	<0.01**	0.746	162.20	10.24	3.32

This indicated that the fertility gradient was created in respect of available soil nitrogen, phosphorus and potassium. Fertility ranges of SN, SP and SK values were mainly due to differential application of fertilizers in the preceding crop. However, local heterogeneity of the soil also contributed partly to this range of variations. Thus experimental field was suitable for soil test crop response studies for the next season crop. Similar type of significant fertility gradient build up have been also reported by Singh*et al.* [15] and Arya[16].

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4. CONCLUSION

Incorporation of graded levels of nutrients (NPK) resulted in significant variations in oat yield, nutrient uptake, and soil fertility between strips. Followed the same trend as the applied fertilizer nutrients, i.e. strip III > strip II > strip I. This variation in the strips with regards to soil fertility was prerequisite for studies on inductive approach and calculating the basic parameters and fertilizer prescription equations for calibrating fertilizer doses for desired target yield of different crops.A short-term exhaust crop is grown in order to transform fertilizer in the soil with plant and microbial activities.

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REFERENCES

1. Tandon, H.L.S.Fertilizers in Indian agriculture from 20th to 21st century.2004.

2. PahalviH., Majeed L., Rashid S., NisarB., Kamili, A. Chemical Fertilizers and Their Impact on Soil Health. 2021.

3. DeyP. Soil Test Crop Response: What Can Be Learnt? In book: National Dialogue on Efficient Nutrient Management for Improving SoilHealth. TAAS, ICAR, CIMMYT, IPNI, CSISA, FAI Editors: ML Jat, K Majumdar, A McDonald, AK Sikka, RS Paroda. 2015.

4. http://www.fao.org/faostat/en/ Food and Agriculture Organization of Unite Nations, 1/02/2023.

5. Ramamoorthy B., Narasimham RL and Dinesh RS. Fertilizer application for specific yield target of sonara-64 wheat. Ind. Farming. 1967;17: 43– 45.

6. Bower CA and Wilcox LA. Methods of soil analysis. Part-1, chemical and microbiological properties. *1965;* 62: 933-951.

7. Jackson ML. Soil chemical analysis. Prentice Hall. Inc. Englehood cliffs, N.J., USA. 1958.

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8. Walkley A. and BlackCA. An examination of different method for determining soil organic carbon and a roved modification of chromic acid titration method. Soil Sci.*; 1934;*37: 29-38.

9. Subbiah AV and Asija GL. A rapid procedure for assessment of available nitrogen in rice plots. Current Sci. 1956;31: 196-200.

10. Olsen SR, Cole CV, WatandbeFS and Dean LA. Estimation of available Phosphorus in soil by extraction with Sodium Bicarbonate. J. Chem. Inf. Model. 1954; 53 (9):1689-1699.

11. Hanway JJ and HiedalH.Soil analysis method used in Iowa State soil testing laboratory. Iowa Agric.1952; 57: 1-31.

12. ChoudhuryP.Use of STCR approach for optimization of integrated nutrient recommendation to obtain better growth and yield of Urd (Vignamungo L.) grown in mollisol of Uttarakhand. Thesis, Master of Science, G. B. Pant Universityof Agriculture and Technology, Pantnagar, Uttarakhand, India. 278p; 2021.

13. Verma M, Singh YV, Ajay Babu, Verma S, Meena, R and SahiSK. Soil test crop response based gradient experiment on rice (*Oryza sativa* L.) to fertilisers in the alluvial soil. Ind. J. Agri. & Allied Sci., 2014; 1(4): 51-53.

14. Srinivasan S and Angayarkanni A. Effect of INM on yield and nutrient uptake by rice in STCR experiment. Agric. Sci. Digest. 2008; 28(2): 130-132.

15. SinghVK,Gautam P, Singh S, PareekN and Singh VP. Evaluation of soil fertility gradient experiment on the basis of crop yield, nutrient uptake and soil fertility. Int. J. Curr. Microbiol. App. Sci.2020; 9(02): 2435-2440.

16. AryaA. Optimization of fertilizer doses through STCR approach for Cauliflower (*Brassica oleracea* L.) grown in Mollisols. Thesis, Ph.D. G.B. Pant University of Agriculture and Technology, Pantnagar, 203; 2019.

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