International Journal of Plant & Soil Science

Volume 35, Issue 19, Page 1053-1058, 2023 ; Article no.IJPSS.104584
ISSN: 2320-7035

Establishment of Soil Fertility Gradient and Its Statistical Verification Based on Soil and Crop Response

Akshay Shrivastav [a*], Ajaya Srivastava [a], Raj Bahadur [a] and Pradip Dey [b]

[a] G B Pant University of Agriculture and Technology, Pantnagar, Uttarakhand, India.
[b] AICRP (STCR), Indian Institute of Soil Science, Bhopal, Madhya Pradesh, India.

Authors' contributions

This work was carried out in collaboration among all authors. Author Akshay Shrivastav collected all observation on field, carried out nutrient determination, performed the statistical analysis, wrote the protocol, and wrote the first draft of the manuscript. Author Ajaya Srivastava designed the study and provided all necessary facilities required for the experiment. Author RB did supervision of field. All authors read and approved the final manuscript.

Article Information

DOI: 10.9734/IJPSS/2023/v35i193642

Open Peer Review History:
This journal follows the Advanced Open Peer Review policy. Identity of the Reviewers, Editor(s) and additional Reviewers, peer review comments, different versions of the manuscript, comments of the editors, etc are available here: https://www.sdiarticle5.com/review-history/104584

Original Research Article

Received: 20/06/2023
Accepted: 22/08/2023
Published: 30/08/2023

ABSTRACT

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 Norman. E. Borlaug Crop Research Centre, G.B.U.A.&T, Pantnagar, Uttarakhand, India during *rabi* 2020–21. The experimental field was partitioned into three identical strips. In strip I, $N_0P_0K_0$ was applied, while strip II received $N_{100}P_{100}K_{100}$, and strip III was treated with $N_{200}P_{200}K_{200}$ fertilizers. Nutrient sources included of N:P:K mixture, urea, single superphosphate, and muriate of potash. Oats were cultivated as the exhaust crop, following recommended agronomic procedures, and were harvested upon reaching maturity. Samples of both grain and straw were collected from each strip. The nitrogen, phosphorus, and potassium contents of these samples were assessed, and the total nutrient

**Corresponding author: E-mail: shrivastavakshay1994@gmail.com;*

uptake was calculated. A short-term exhaust crop is grown to transform fertilizer in the soil with plant and microbial activities.

Keywords: Soil fertility gradient; oat; STCR; inductive approach; nitrogen; phosphorus; potassium; nutrient uptake; yield and Mollisol.

1. INTRODUCTION

Nutrient management encompasses strategies aimed at ensuring crops receive optimal quantities of essential nutrients to foster their growth and development. The judicious application and management of nutrient practices across diverse environments and agricultural systems play a pivotal role in augmenting farm productivity, optimizing resource utilization, bolstering food grain output, and mitigating environmental hazards. Fertilizer application constitutes a significant expense in crop cultivation, and the precise optimization of fertilizer quantities holds paramount significance for both economic viability and ecological sustenance. Excessive fertilization can result in the squandering of valuable resources and adverse environmental repercussions. Conversely, insufficient fertilization may lead to diminished crop yields and reduced product quality. Hence, adherence to recommended guideline and the utilization of soil analyses to ascertain the suitable dosage and type of fertilizers become imperative. Notably, fertilizer consumption in India has experienced a substantial surge over recent decades.

“However, it is important to note that Indian agriculture currently has a 'net negative nutrient balance' of 8-10 million tons per year , which is expected to increase to around 15 million tons by 2025” [1]. “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. The Soil Test Crop Response (STCR) approach takes into account, the amount of nutrient removed by the crop, the initial level of soil fertility, and 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” [4].

“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 a definite advantage in terms of increasing nutrient response ratio over the general recommended dose of nutrient application” [3]. Singh et al. (2021) concluded similar study for optimization of fertilizer for DSR-Wheat cropping sequence [5].

“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 a maximum area in Uttar Pradesh (34%), followed by Punjab (20%), Bihar (16%), Haryana (9%) and the rest of the area is shared by Gujrat, Orissa, Uttarakhand, etc. As of May 2021, oat is seventh in world cereal production” [6]. 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.

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.

2. MATERIALS 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" [7]. 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.

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, 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 fertilizer nutrients N, P_2O_5, and K_2O ($N_0P_0K_0$, $N_{100}P_{100}K_{100}$, 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 the 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.

Soil samples were obtained from the surface layer prior to the sowing of the exhaust crop, air dried in the shade, processed, and used in chemical analysis for EC [8], soil pH [9], soil organic carbon [10], available nitrogen by alkaline $KMnO_4$ method [11], available phosphorus by Olsen's method [12] and available potassium by neutral normal ammonium acetate [13]. 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.

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.

3.2 Yield and Nutrient Uptake by Exhaust Crop Oat

The investigation showed significant outcomes pertaining to the application of varied nutrient levels (N, P_2O_5, and K_2O) on both the yield and nutrient uptake of the oat exhaust crop, as presented in Table 2. The findings from the experiment involving a soil fertility gradient revealed distinct performance among three strips. Strip III exhibited the highest dry matter yield for the exhaust crop, reaching 181.11 q ha^{-1}, followed by strip II with 162.94 q ha^{-1}, and finally strip I, registering the lowest yield at 138.73 q ha^{-1}. The respective green forage yields for strips I, II, and III were recorded as 350.25 q ha^{-1}, 422.48 q ha^{-1}, and 452.57 q ha^{-1}. Notably, in strip III, where N, P_2O_5, and K_2O fertilizers were applied at twice the rate of strip II, the green forage yield experienced an increase of 29.21% and 7.12% when compared to strip I and II, respectively. Similarly, the dry matter yield saw an escalation of 30.54% and 11.15% in comparison to strip I and II, respectively. This trend suggests that the gradual augmentation of nutrient application positively influenced nutrient uptake and growth parameters. This observation aligns with the findings of Choudhury [14], who noted enhanced grain and straw yields in sorghum crops through the application of graded fertilizers across a gradient.

"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 a maximum of 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 of 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 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, which were the cause of the increased phosphorus uptake" [15].

"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 were observed by Srinivasan and Angayarkanni" [16].

3.3 Soil Fertility Status after the Harvest of Exhaust Crop

Strip-wise average soil test values after the harvest of exhaust crop showed the 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. The 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. The 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. The average soil test value of available potassium was 156.57, 162.73 and 167.32 kg K ha^{-1} in strips I, II and III, respectively. Soil test values of alkaline KMnO4-N, Olsen's-P and NH4OAc-K were highest in strip III followed by strip II and the least in strip I. The 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). The 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 [17].

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 variables separately, the effect of the strip was highly significant.

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 has been also reported by Singh et al. [17] and Arya [18].

Table 1. Nutrient doses applied in soil fertility gradient experiment with oat crop [4]

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

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

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

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

4. CONCLUSION

The incorporation of progressively graded levels of nutrients encompassing nitrogen (N), phosphorus (P), and potassium (K) engendered significant variation in oat crop yield, nutrient uptake by plants, and soil fertility across distinct strips. This variation exhibited a consistent pattern, mirroring the sequential application of fertilizing nutrients, strip III reported superior performance relative to strip II, and subsequently to strip I. This variance in soil fertility distribution among the strips were foundational prerequisite for studies on inductive approach. It facilitated the derivation of basic parameters and equations for the precise fertilizer dosages requisite to achieve targeted yields for different crops. In tandem, A short-term exhaust crop is grown to transform fertilizer in the soil with plant and microbial activities.

CONFERENCE DISCLAIMER

Some part of this manuscript was previously presented in the conference: 6th International Conference on Strategies and Challenges in Agricultural and Life Science for Food Security and Sustainable Environment (SCALFE-2023) on April 28-30, 2023 in Himachal Pradesh University, Summer Hill, Shimla, HP, India. Web Link of the proceeding: https://www.shobhituniversity.ac.in/pdf/Souvenir-Abstract%20Book-Shimla-HPU-SCALFE-2023.pdf

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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Peer-review history:
The peer review history for this paper can be accessed here:
https://www.sdiarticle5.com/review-history/104584