Asia Pacific Academy of Science Pte. Ltd.

Advances in Modern Agriculture 2024, 5(1), 2401.
https://doi.org/10.54517/ama.v5i1.2401

Article

A new approach to measure spatial variability of soil parameters and field technique to test-value specific fertilizer recommendations

Hari Dahal

Faculty of Agriculture, Food Security and Research College of Applied Sciences, Tribhuvan University, Kathmandu 44600, Nepal; dahaldr.hari@gmail.com

CITATION

Dahal H. A new approach to measure spatial variability of soil parameters and field technique to test-value specific fertilizer recommendations. Advances in Modern Agriculture. 2024; 5(1): 2401. https://doi.org/10.54517/ama.v5i1.2401

ARTICLE INFO

Received: 29 November 2023
Accepted: 3 January 2024
Available online: 29 February 2024

Abstract: Information on the distribution of soil properties is important to know the status of nutrients in the soils based on which fertilizer nutrients are recommended. Given the variability of nutrients in the soils, making a site-specific fertilizer recommendation seems to be a compelling work. To determine the spatial variability of soil nutrients and to make judicious and precise fertilizer recommendations, new measures are designed with this study. These measures are tested against the soil samples (*n* = 43) for total nitrogen (N), organic matter (OM), phosphorus (P_2O_5), and potassium (K_2O) in the study area. The descriptive statistical analysis indicated an average of low nitrogen and organic matter, while phosphorus was found to be very high and the level of potassium was high. The spread of nutrients across the data sets, however, included low, medium, high, and very high levels of ratings. The Deviation Square Index was developed and applied for the variability measurement and found that the largest variation was with phosphorus distribution, followed by potassium, nitrogen, and organic matter. The coefficient of variation (CV%) analysis also exhibited similar trends in nutrient distributions. Nitrogen was the main determinant explaining the variations in rice yield, while phosphorus and potash were negatively related to the yield. An index of fertilizer nutrient recommendation called Test-Value Specific Dose (TVSD) was developed and used to calculate the nutrient recommendation for each sampled location. This new method gave easy and more accurate doses of fertilizer over the blanket recommendation to fit the variations across the soil samples.

Keywords: spatial variability; soil nutrient distribution; SSNM; deviation square index; test value specific dose; fertilizer recommendation

1. Introduction

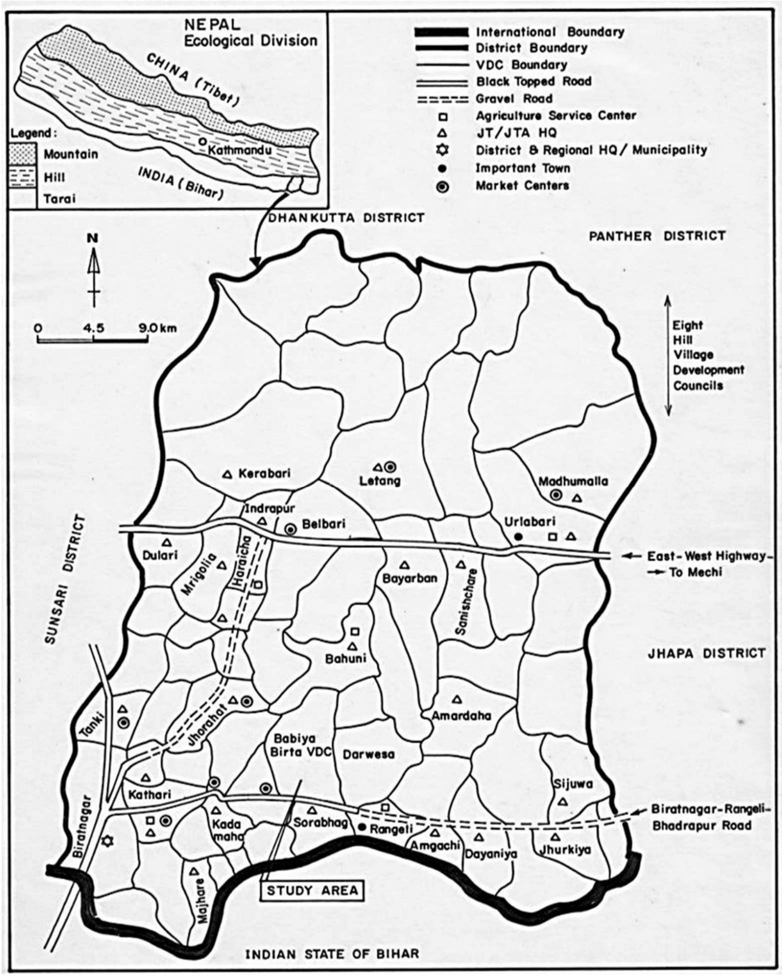
In nature and on agricultural lands, soils are inherently heterogeneous. The heterogeneity is due to various geochemical processes and also to agricultural activities such as crop cultivation and soil management practices [1]. Because of variability in soil parameters and other natural resources, farm soils are not uniformly fertile and productive. As there is little information about the levels and distribution of soil nutrients in each location and field, the general practice is to recommend a blanket fertilizer application to crops, leading to imbalanced fertilization, declined productivity, and eventually degradation of soils. It is, therefore, necessary to assess the spatial distribution of soil nutrients to ensure precise nutrient management, enhance crop yields, and achieve sustainability in agriculture [2,3]. Assessing the spatial variability of soil properties also helps improve input use efficiency and cost-effectiveness, and reduces environmental degradation [4]. Site-specific nutrient management (SSNM) is also dependent on the knowledge of nutrient distributions in the soils. Knowledge of the spatial variability of soil properties greatly helps in identifying production constraints, specific nutrient needs of crops, and overall nutrient management [5].

The objective of this study is to assess the general status of major soil nutrients (total nitrogen (N), phosphorus (P_2O_5), and potassium (K_2O), including organic matter (OM), and their variability across the study area. It also aims to make soil test value-specific fertilizer nutrient recommendations based on the spatial variability of nutrients for farmers. Conventionally, soil analysis is limited to the quantification of soil parameters and is not focused on how they vary spatially. The latter aspect of soil analysis is therefore addressed in this study using simpler and more practical methods compared to geo-statistical techniques, based on which a more accurate method of nutrient recommendation is proposed.

2. Materials and methods

2.1. Study area

The study site of the then Babiyabirta village development committee (now 1 and 2 wards of Rangelee Urban Municipality) is located about 17 km east of Biratnagar along the Biratnagar-Rangelee road, and Babiyabirta bazar (26.49° N and 87.43° N) is 6 km to the north of the road (**Map 1**). The cultivated land area was 3242 ha, of which about 73% was lowland paddy fields. The area, which is also an extension of the Indo-Gangetic Plain is flat land with slope gradients ranging from 0.5% to 0.2% from north to south. The elevation ranges from 60 m to 70 m above the mean sea level (MSL). The soils are alluvial, mostly loam and sandy loam, and are slightly acidic to slightly alkaline, making them suitable for the major field crops that are grown in the area. The climate is subtropical, hot, and humid. The mean annual rainfall ranges from 1400 mm to 2110 mm. The wettest months are from June to September, receiving about 80% of total annual precipitation. Rice (Oryza sativa) based cropping patterns were widely practiced, and different varieties of rice were grown in the area. Next to rice were maize (Zea mays), wheat (Triticum sativum), mustard (Brassica juncea), pulses-lentil (Lens culinaris), Chickpea or gram (Cicer arietinum), pigeon pea (Cajanus cajan), and cowpea (Vigna sinensis). Other crops were grown in smaller areas.



Map 1. Map of the study area.

2.2. Sampling design

Soil samples should be appropriate in number and accurate to reflect the true nutrient status of the field. A well-designed sampling can also reflect changes in soil fertility, which will be the basis for fertilizer recommendations and improve nutrient use efficiency, leading to an increase in return on investment on fertilizers [6]. Soil is a dynamic system, and nitrogen in particular makes it difficult to predict its availability over time. The levels of other key nutrients in the soil keep changing too, due to cultivation practices and climate impacts. It is therefore recommended to take soil sampling every 1 to 3 years [7,8]. In light soils where rainfalls are high and more frequent irrigations are given, soil samples should be taken annually [9].

There are different techniques of soil sampling, and W-Pattern is one of them that can give a representative sample for each field or paddock. As the landholding for the majority of the farmers was small, 50 m × 50 m areas were selected for soil sampling for each location. With the help of a spade and augur, samples were taken in W-Pattern randomly from a plow depth of 20–25 cm. In order to capture the spatial range of variation, 7 subsamples from location 1 (Manglabare) and 6 subsamples from location 2 (Betauna) were taken. Similarly, 5 subsamples from other locations—Dhimdhime, Bhedibathan, Bhaluwa, Latamorang, Birta bazar, and Sagardina were collected. Altogether, 43 samples were taken. The samples were air-dried and ground to pass through a 2 mm sieve. To make a composite sample, subsamples for each location were thoroughly mixed and reduced by successive quartering to become about half a kilogram. Samples were put into plastic bags, and crop and fertilizer history, along with the farmer's name and address, were labeled on the respective sample bag and taken to the Regional Soil Laboratory, Tarhara, Sunsari, for analysis.

2.3. Soil analysis

Organic matter and total nitrogen percentage were determined as a measure of carbon content by the Walkley Black Rapid Titration method. Phosphorus kilogram per hectare was estimated by Olsen's sodium bicarbonate method, and potash kg per ha was measured by the Potash Turbid metric method. The soil pH was determined in a 1:1 soil-water suspension with a digital glass electrode pH meter.

2.4. Statistical analysis

To know the central tendency and spread of data, descriptive statistics such as mean, standard deviation, minimum and maximum values, coefficient of variation, skewness, and kurtosis were analyzed. Pearson's correlation was used to see the correlation coefficient between two variables. To know whether soil properties follow a normal distribution, a QQ plot analysis was done. To know the variables that are important to crop yield, multiple linear regression was performed.

2.5. Spatial variability analysis

The analysis of the spatial variability of the data was carried out with a newly constructed index called the Deviation Square Index (DSI). This is the index that determines whether the soil properties observed in the selected samples differ significantly from one another. The index is expressed as Equation (1):

$$\frac{\sum(x-\bar{x})^2}{\sum(x-\bar{x})^2+\sum x(2n-m)} \tag{1}$$

where, x = individual observation; $\bar{x}$ = mean of the x value; $\sum(x-\bar{x})^2$ = sum of square mean deviation; $\sum x$ = sum of the observations; n = number of observations (or sample size); m = maximum minimum difference ratio (maximum − minimum) ÷ minimum.

The DSI is a ratio of the amount of observed variation to the maximum variation that could exist in the data distribution. The value of the index ranges from 0 (total lack of variation) to 1 (maximum variation). For smaller values that we usually get in the measurements of organic matter (OM) and total nitrogen (N), this index does not give good results. For this kind of situation, we can use a slightly different index, which we can call the Mean Deviation Square Index (MDSI) and is expressed as Equation (2):

$$\frac{(n-1)\{\bar{x}^2-\sum(x-\bar{x})^2\}}{\bar{x}^2(n+1)} \tag{2}$$

The notations are the same as in the DSI.

2.6. Fertilizer nutrient calibration methods

The conventional method of fertilizer nutrient recommendation based on soil test results is a *blanket recommendation.* This method does not fit in areas where spatial variations of soil parameters are large, as is the case, in most cultivated lands. Soil parameters vary from plot to plot and within the plot. It is therefore critical that these variations are captured precisely and recommendations be made specifically to address the nutrient status in the soils, not in a blanket manner. The more accurate method for this purpose can be called a Test Value Specific Dose (TVSD), which is expressed as Equation (3):

$$\text{TVSD} = \frac{\bar{x}}{T_v} z * a \tag{3}$$

where, $\bar{x}$ = mean of test values; z = blanket recommended nutrient dose; T_v = test value; a = A regulating constant, the value of which is 1 for very low soil test value, 0.75 for low value, 0.55 for medium value, and 0.25 for high soil test value. The figure is not assigned for very high soil test values, as we do not recommend fertilizer for this range of soil tests.

This index is used for nitrogen recommendations. The TVSD value can be reduced if other sources of nutrients are available, multiplied by a correction factor. It gives a reduced dose of nutrients that come from fertilizers. (Equation (4))

$$\text{TVSD with a correction factor} = \frac{\bar{x}}{T_v} z|\text{Tv} - 1|/\text{TV} + 1 \tag{4}$$

For phosphorus and potash recommendations, we multiply T_v by a constant *(k)* as is given in Equation (5).

$$\frac{\bar{x}}{T_{v(k)}} z \tag{5}$$

where, $\bar{x}$ = mean of test values; T_v = test value; Z = blanket recommended nutrient dose; k = constant, the value of which is 10 for very high-test value, 8 for high value, 6 for medium value, 4 for low value, and 2 for very low value.

3. Results and discussions

3.1. Descriptive statistics

The soil parameters distributed by location are shown in **Table 1**. Not all of the data figures are the same. In most locations, nitrogen levels are low, except in two locations that have medium levels of nitrogen. The organic matter varies between 1.6 to 2.46; all values, however, fall under a low rating. Phosphorus varies from low 62 to high and very high 337 kg per hectare. Similarly, potassium level is distributed among low, medium, and high levels.

Table 1. Soil parameters are distributed by locations in the study area.

Location	Nitrogen%	*OM*%	*P* kg/ha	*K* Kg/ha
L1	0.1068	2.14	106	256
L2	0.1052	2.10	94	103
L3	0.1227	2.46	337	383
L4	0.0973	1.95	219	398
L5	0.0998	1.99	62	300
L6	0.1173	2.41	155	427
L7	0.0801	1.6	170	197
L8	0.0969	1.9	71	308

L1 = Manglabare, L2 = Betauna, L3 = Dhimdhime, L4 = Bhedibathan, L5 = Bhaluwa, L6 = Latamorang, L7 = Birta and L8 = Sagardina. *OM* = Organic Matter, *P* = Phosphorus, *K* = Potassium.

The descriptive statistics are presented in **Table 2**. The central tendency of the means was low ($\bar{x}$ = 0.1033) for nitrogen and also low ($\bar{x}$ = 2.0688) for organic matter. The average level of phosphorus was very high ($\bar{x}$ = 151.75), whereas potassium was high ($\bar{x}$ = 296.5). The coefficient of variation that shows the variability of the data sets was the largest (CV% = 60.6) for phosphorus, indicating a large variation in the distribution of phosphorus at different locations. With 37% CV, the potassium distribution was the second largest. Unlike phosphorus and potassium, organic carbon and total nitrogen had less heterogeneity. Organic matter and nitrogen data sets have low skewness and low coefficients of variation. Skewness for phosphorus was positively skewed (1.257), whereas for potash it was slightly negatively skewed (−0.635). The values of kurtosis show that data distributions were neither too peaked nor too flatter.

Table 2. Descriptive statistical analysis.

Parameter	Mini	Maxi	Sum	Mean	SD	CV(%)	Skewness	Kurtosis
OM	1.60	2.46	16.55	2.0688	0.27880	13.48	−0.087	0.000
TN	0.08	0.1227	0.8261	0.1033	0.01318	12.76	−0.231	0.473
Phosphorus	62.00	337.00	1214.00	151.75	91.95302	60.60	1.257	1.436
Potassium	103.00	427.00	2372.00	296.50	109.50669	36.93	−0.635	−0.239

The normality test was also performed on a quantile-quantile (QQ) plot and found that none of the soil properties followed exactly the straight diagonal line (**Figure 1**). It means all four properties (*OM*, *TN*, *P*, and *K*) have shown that the quantile points do not lie on the theoretical normal distribution line.

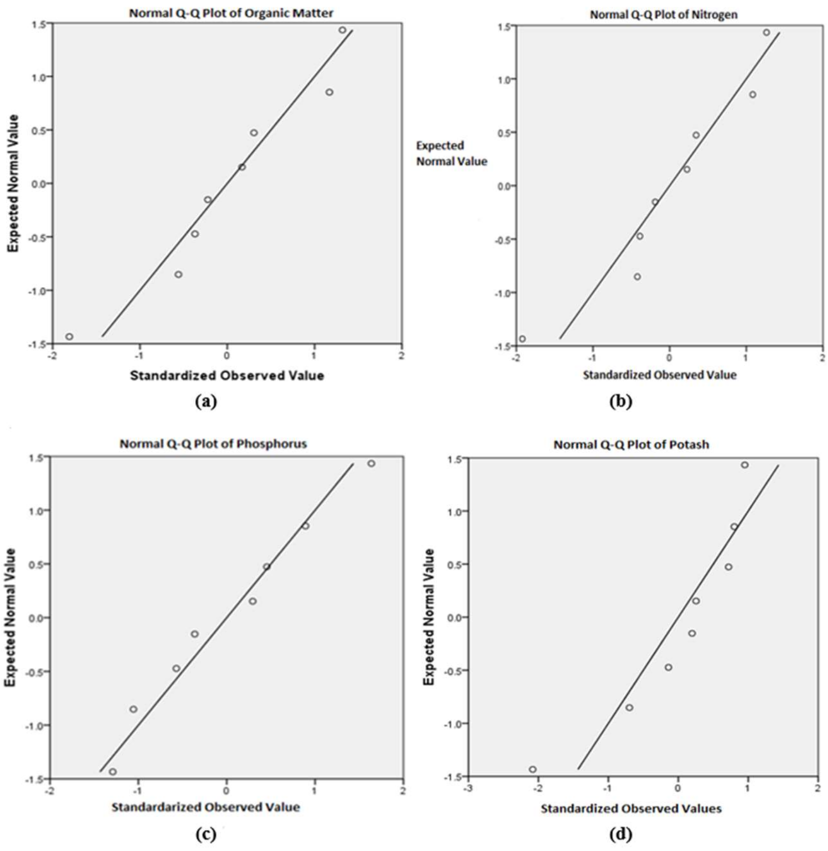


Figure 1. Showing Q-Q plot for nitrogen, organic matter, phosphorus, and potash.

3.2. Variables important to rice yield

To identify the important variables explaining variations in rice yield, multiple linear regression models were employed for the data shown in Appendix **Table A1**. The general form of multiple linear regressions is given by Equation (6).

$$Y = b_o + b_1 x_1 + b_2 x_2 + \ldots + b_k x_k + e \quad (6)$$

The dependent variable Y is regarded as a function of k independent variables x_1, x_2, and x_k. The coefficients b_1 to b_k are referred to as the partial regression coefficients, which in fact determine the contribution of the independent variables in the equation, and b_o is the y-intercept. The random error term (e) is a random variable with a mean of zero and a standard deviation of σ. The multiple linear regression outputs are shown in **Table 3**. The unitary R^2 and R^2 adjusted values show the best fit of the data, while the highly significant F value indicates the significance of the model. The largest beta (0.782) and t (17.471) values indicate nitrogen as the most important variable among all variables to determine the variation of yield in the study area. All variables except phosphorus were significant. Since P and K were very high and high, respectively, in the soil, both of them were negatively related to rice yield. It means additional applications of these fertilizer nutrients are not economical for farmers. Access to irrigation and application of fertilizer (which includes mainly urea) were significant and positively related to the yield.

Table 3. Regression outputs.

Variable	Coefficients				
	B	**SE**	**Beta**	***T* value**	**Sig**
Constant	−853.697	72.482	-	−11.778	0.007
Nitrogen	31,457.314	1800.518	0.782	17.471	0.003
Phosphorus	−0.008	0.073	−0.001	−0.106	0.925
Potassium	−0.609	0.051	−0.131	−11.890	0.007
Fertilizer	9.126	2.258	0.099	4.041	0.056
Irrigation	8.538	1.323	0.213	6.456	0.023
R^2	1, R^2 adjusted 0.999, F value 2473.032(Sig 0.000)				

3.3. Spatial distribution of soil parameters

To get a single measure of the spatial distribution of soil parameters, a new technique called Deviation Square Index (DSI) is used for the first time. With this index, phosphorus exhibited a value of 0.808 (**Table 4**), which is interpreted against **Table A2** (Appendix). The value indicated a high variation of phosphorus levels across the eight locations. To determine whether soil properties observed in the selected samples differ significantly from an even distribution, we can use the table of critical values for Pearson's r. The null hypothesis for this test can be formulated as H_0: The nutrient contents in the soil samples are uniformly distributed.

Table 4. Phosphorus distribution and deviation square computation.

Location	x	$(x-\bar{x})$	$(x-\bar{x})^2$
1	106	−45.75	2093.0625
2	94	−57.75	3335.0625
3	337	185.25	34,317.5625
4	219	67.25	4522.5625
5	62	−89.75	8055.0625
6	155	3.25	10.5625
7	170	18.25	333.0625
8	71	−80.75	6520.5625
-	$\sum x$ = 1214	-	$\sum(x-\bar{x})^2$ = 59,187.5

The Pearson r critical value at the 0.05 level of significance for $n - 1 = 7$ degrees of freedom is 0.666 (Table not shown), which is less than the calculated value of 0.808 (Equation (7)). The null hypothesis that the P_2O_2 distribution across the samples or locations is the same is rejected. The observed differences between the locations seem to be real and could not have occurred due to chance. The conclusion of the test is that for each location, phosphate fertilizer application needs to be different, and blanket application may neither be profitable to farmers nor friendly to the soil and environment.

$$\text{Deviation Square Index(DSI)} = \frac{\sum(x-\bar{x})^2}{\sum(x-\bar{x})^2 + \sum x(2n-m)} = \frac{59187.5}{59187.5 + 1214[(2*8) - 4.44]} = 0.808 \quad (7)$$

The potassium (K_2O) distribution in the study area was mostly high, but medium and low levels were also found (**Table 5**). As shown in Equation (8), the Deviation Square Index was calculated to be 0.734, which means there is a high variation in the distribution of potassium in the study area. To test the null hypothesis that the potassium distribution was uniformly distributed across the samples, Pearson's critical value of 0.666 for $n - 1 = 7$ degrees of freedom was less than the calculated value (0.734), and the null hypothesis was rejected. As the variations in the distribution of potassium were high, a blanket recommendation of fertilizer nutrients was not rational.

$$\text{DSI} = \frac{\sum(x-\bar{x})^2}{\sum(x-\bar{x})^2 + \sum x(2n-m)} = \frac{83942}{83942 + 2372\ [(2*8) - 3.15]} = 0.734 \quad (8)$$

Table 5. Potash distribution and deviation square computation.

Location	x	$(x-\bar{x})$	$(x-\bar{x})^2$
1	256	−40.5	1640.25
2	103	−193.5	37,442.25
3	383	86.5	7482.25
4	398	101.5	10,302.25
5	300	3.5	12.25
6	427	130.5	17,030.25
7	197	−99.5	9900.25
8	308	11.5	132.25
-	$\sum x$ = 2372	-	$\sum(x-\bar{x})^2$ = 83,942

To measure spatial variations of organic matter and nitrogen Mean Deviation Square Index (MDSI), Equation (2) is used, as shown in Equations (9) and (10). Organic matter and nitrogen distributions are similar, as Pearson's correlation coefficient (r) of these two parameters was found to be highly significant (0.996 at 0.01 levels). Their distributions and MDSI values are moderate and nearly the same (**Tables 6** and **7**), and both are significant at 0.05 for 7 degrees of freedom in Pearson's correlation critical table. This means the blanket recommendation of nitrogen is not suitable across the sampled locations.

$$\text{Mean Deviation Square Index (MDSI)} = \frac{n-1\{\bar{x}^2 - \sum(x-\bar{x})^2\}}{\bar{x}^2(n+1)} = \frac{7\{(0.1033)^2 - 0.00121567\}}{(0.1033)^2(9)} = 0.689 \quad (9)$$

$$\text{MDSI} = \frac{n-1\{\bar{x}^2 - \sum(x-\bar{x})^2\}}{\bar{x}^2(n+1)} = \frac{7\{(2.06875)^2 - 0.5440877\}}{(2.06875)^2(9)} = 0.678 \quad (10)$$

Table 6. Nitrogen distribution and mean deviation square index.

Sample	(x)	$(x-\bar{x})$	$(x-\bar{x})^2$
1	0.1068	0.0035	0.00001225
2	0.1052	0.0019	0.00000361
3	0.1227	0.0194	0.00037636
4	0.0973	−0.006	0.000036
5	0.0998	−0.0035	0.00001225
6	0.1173	0.014	0.000196
7	0.0801	−0.0232	0.00053824
8	0.0969	−0.0064	0.00004096
	$\bar{x}$ = 0.1033	-	$\sum(x-\bar{x})^2$ = 0.00121567

Table 7. Organic matter distribution and mean deviation square index.

Sample	(x)	$(x-\bar{x})$	$(x-\bar{x})^2$
1	2.14	0.07125	0.0050766
2	2.10	0.03125	0.00097656
3	2.46	0.39125	0.1530766
4	1.95	−0.11875	0.0141016
5	1.99	−0.07875	0.00620156
6	2.41	0.34125	0.1164516
7	1.6	−0.46875	0.2197266
8	1.9	−0.16875	0.0284766
	$\bar{x}$ = 2.06875	-	$\sum(x-\bar{x})^2$ = 0.5440877

3.4. Test-value specific (TVS) fertilizer recommendations

A blanket approach to fertilizer nutrient recommendations has been a long-held tradition in Nepal. Recently, after decades of blanket applications, new recommendations have been made for different regional domains [10]. The site-specific nutrient management (SSNM)—a field-specific fertilizer recommendation is now being promoted widely. However, it does not say anything about the size of a site or field. This is a plant-based approach to feeding nutrients at optimum rates as and when needed to achieve high nutrient efficiency and crop yield [11,12]. Fertilizer recommendations based on soil test values are, however, the norm in countries like Nepal.

A more judicious and practical approach to fertilizer nutrient recommendations is therefore developed to address the variability of soil nutrients in farmers' fields. According to which nutrients are applied in the right amount and to the right soil cores or locations from where soil samples were collected. The soil test values, blanket recommendations, and test value specific dose (TVSD) are calculated and recommended for NPK application to rice crops in the study area and are given below (**Tables 8–10**). The dose of fertilizer nitrogen based on the levels of soil nitrogen is calculated as follows:

Table 8. Nitrogen levels in the soils and TVSD kg/ha.

Location	*N* (%)	*Z*	TVSD*
1	0.1068	110	80
2	0.1052	110	81
3	0.1227	110	51
4	0.0973	110	88
5	0.0998	110	85
6	0.1173	110	53
7	0.0801	110	106
8	0.0969	110	88

X = Test Value, *Z* = Blanket Recommended dose kg per ha; *Figures are rounded up to the nearest whole number; TVSD = Test Value Specific Dose; $\bar{x}$ = 0.1033 (Low).

Table 9. Phosphorus levels in the soils kg/ha and test value specific dose (TVSD).

Location	Test value (Tv)	*K* (Constant)*	*Z*	TVSD** (kg/ha)
1	106	H (8)	30	5
2	94	H (8)	30	6
3	337	VH (10)	30	1
4	219	VH (10)	30	2
5	62	H (8)	30	9
6	155	VH (10)	30	3
7	170	VH (10)	30	3
8	71	H (8)	30	8

*H = high, VH = very high, *Z* = blanket recommended dose in kg/ha **Figures are rounded up, $\bar{x}$ = 151.75 (Very high).

Table 10. Potassium levels in the soils kg/ha and test value specific dose (TVSD).

Location	Test value (Tv)	*K* (Constant)*	*Z*	TVSD** (kg/ha)
1	256	M (6)	30	6
2	103	L (4)	30	22
3	383	H (8)	30	3
4	398	H (8)	30	3
5	300	H (8)	30	4
6	427	H (8)	30	3
7	197	M (6)	30	8
8	308	H (8)	30	4

*L = low, M = medium, H = high, VH = very high, **Figures are rounded up, $\bar{x}$ = 296.5 (High).

The TVSD for phosphorus and potash is calculated by making use of index 5 (page 4) for each level of soil nutrient status across the data set and is presented in **Tables 9** and **10**, respectively.

Test Value Specific Dose (TVSD) $= \frac{\bar{X}}{T_v} * z * a = \frac{0.1033}{0.1068} * 110 * 0.75 =$ 80 kg per ha (1st location in **Table 8**). Similarly, TVSD for all sampled locations is calculated and given for each of the test values of nitrogen in **Table 8**. The test value-specific doses of fertilizer nutrients are different for different locations according to the soil nutrient levels. Since there are no very low, high, or very high values, the fertilizer nutrient doses vary from a low of 51 kg per hectare for a medium level of nitrogen in the soil (0.1227) to as high as 106 kg for a low (lowest among the low) value of nitrogen (0.0801) per hectare for irrigated rice. These doses are far more judicious and logical than a blanket recommendation of 110 kg per hectare for the whole country, region, or domain. This method gives higher fertilizer doses to lower soil test values and lower fertilizer nutrients to higher soil test values.

There seems to be an inverse relationship between soil fertility levels and the probability of a profitable crop response, provided other things are equal. The general rule of thumb is that at a very low level.

The fertilizer recommended dose is profitable; at a medium test value, half of the recommended dose is profitable; and at a high level, 1/4 of the recommended dose is profitable. At very high levels, no fertilizer nutrient is recommended [13,14].

3.5. Discussions

The findings show moderate to high soil nutrient variability across the study area. Nitrogen is the most important nutrient element but also the most frequent deficit nutrient. Its inadequacy is considered to be a major cause of low crop yields in Nepal [15,16]. The average level of nitrogen was found to be low, some 56% of the households in the study area reported low levels of nitrogen in their soils. This finding corroborates the annual report of the Department of Agriculture (Soil Management Directorate), in which out of 16,345 samples analyzed, 56.25% of them had low nitrogen [17]. In their study, Tandan et al. [18] reported similar results of nitrogen status (0.05 to 0.12) at a nearby village of Jhorahat in Morang district. They found out that about 75% of the area had a low distribution of nitrogen. In the study area, 44% of the households nevertheless had medium levels of nitrogen.

As organic matter and nitrogen are highly correlated (Pearson's correlation coefficient, $r = 0.996$), the average level of organic matter was also found to be low (**Table 2**). The rate at which nitrogen is released from organic matter varies with temperature, types of organic matter, moisture level, and microbial decomposition [19]. The low level of nitrogen and organic carbon in the study area is mainly attributed to the cultivation of high nitrogen-demanding crops, crop harvest removal, non-recycling of crop residues, and inadequate manure and fertilizer applications in the field.

Contrary to the findings of the Department of Agriculture (DOA), which reported that 69% of the samples had medium to low levels of phosphorus, the average phosphorus content in the study area was very high (**Table 9**). The exact reason behind high to very high levels of phosphorus is not known, but the presence of phosphoruscontaining parent materials and excessive and repeated use of manures and phosphate fertilizers may have caused the high level of phosphorus in the study area [20,21].

The average potassium level was high, which is not in line with the DOA report (**Table 10**). In this report, 50% of all samples had a low level of potassium, while in the nearby village of Jhorahat, about 90% of the sampled area had a low level of potassium [18]. In a village (Bankatwa) in the Banke district of western Terai, the majority of samples were found to be in the medium to low range [22]. Why the average potassium level is high in the study area is not easy to explain. The presence of potassium-rich minerals in the soil and adding large amounts of manure along with high potassium fertilizers regularly over a long period of time can result in a high level of potassium in the soil. Farmers' practice is that they apply more of the manures to meet the target nitrogen requirement, which causes them to accumulate potassium in excess in the soil [23]. Looking at the relationship between soil nutrients and rice yield, it was found that nitrogen was the most important variable to explain the yield variations. Both phosphorus and potassium were negatively related to rice yield, probably due to their presence at high to very high levels in the soils.

3.6. Fertilizer recommendations

As an alternative to the blanket recommendation, site-specific nutrient management (SSNM) has been appreciated over the years as superior to optimizing the supply of soil nutrients and increasing yield, nutrient use efficiency, and profitability [24,25]. The traditional blanket recommendation is mainly criticized for not having to account for wide variations in soil nutrients. This leads to the application of fertilizer in excess in some areas and under fertilization in other locations, thus causing the misuse of costly resources [26]. SSNM, on the other hand, is highlighted to optimize the supply of soil nutrients to meet crop needs through four key principles, also known as the 4Rs—right fertilizer, right rate, right time, and right place [27]. Nonetheless, these four principles can also be applied to the blanket recommendation, which is a broad, basic, and economical recommendation for larger areas.

SSNM is not entirely lacking constraints. It requires gaining knowledge of the variability of soil parameters and monitoring the nutrient needs of crops to adjust fertilizer inputs at each site or field. Soil test values alone do not indicate the rate at which fertilizer nutrients are to be recommended unless they are calibrated to crop responses to added nutrients [28,29]. As the size of a site is uncertain, making site-specific fertilizer recommendations for numerous locations can be a challenge for farmers, extension workers, and researchers [27,30]. SSNM technologies may be sound and effective; their accessibility, however, is limited to poor and smallholder farmers in terms of associated costs, availability of advisory services in time, and users' characteristics [31,32]. Technological complexity and socioeconomic heterogeneity among users may pose a real threat to scaling up the SSNM approach, particularly in low-income developing countries.

4. Conclusions

The results of the study indicated that the Deviation Square Index (DSI) used to analyze the spatial variability of soil properties was found to be relevant and useful.

The coefficient of variation (CV) also matched the findings of the deviation square method for all soil parameters in capturing the variations in the data sets. As for the fertilizer, unlike blanket recommendations, the test value-specific method offers a sample-specific nutrient application that is a rational, precise, and scientific approach to nutrient management. Furthermore, this method helps improve nutrient use efficiency, lowers costs of crop cultivation by reducing fertilizer overuse and underuse, increases food production, and improves the quality of soil, water, and the environment. To further add to the reliability and validity of this method, field evaluation can be a future course of action to establish its validation.

Acknowledgments: Thanks are due to the anonymous reviewers and the editors for their valuable comments and suggestions.

Conflict of interest: The author declares no conflict of interest.

References

1. Soropa G, Mbisva OM, Nyamangara J, et al. Spatial variability and mapping of soil fertility status in a high-potential smallholder farming area under sub-humid conditions in Zimbabwe. SN Applied Sciences. 2021, 3(4). doi: 10.1007/s42452-021-04367-0
2. Reza SK, Ray P, Ramachandran S, et al. Spatial Distribution of Soil Nitrogen, Phosphorus and Potassium Contents and Stocks in Humid Subtropical North-Eastern India. Journal of the Indian Society of Soil Science. 2019, 67(1): 12. doi: 10.5958/0974-0228.2019.00002.1
3. Ramzan S, Wani MA, Bhat MA. Assessment of Spatial Variability of Soil Fertility Parameters Using Geospatial Techniques in Temperate Himalayas. International Journal of Geosciences. 2017, 08(10): 1251-1263. doi: 10.4236/ijg.2017.810072
4. Yan P, Peng H, Yan L, et al. Spatial Variability of Soil Physical Properties Based on GIS and Geo-Statistical Methods in the Red Beds of the Nanxiong Basin, China. Polish Journal of Environmental Studies. 2019, 28(4): 2961-2972. doi: 10.15244/pjoes/92245
5. Zakaria Y, Shaibu AG, Baatuuwie B. Spatial analysis of soil physicochemical and hydraulic properties in the Libga irrigation scheme in northern Ghana using geostatistics and GIS approach. Soil Science Annual. 2022, 73(2): 1-8. doi: 10.37501/soilsa/149942
6. Ackerson JP. Soil Sampling Guidelines. Purdue University Extension; 2018.
7. UVM. Nutrient Recommendations for Field Crops in Vermont. The University of Vermont; 2018.
8. Warncke D, Dahl J, Jacobs L. Nutrient Recommendations for Field Crops in Michigan. Michigan State University; 2009
9. Nathan MV. Soils, Plant Nutrition and Nutrient Management. Extension, University of Missouri; 2017.
10. International Fertilizer Development Center. Nepal launches site-specific fertilizer recommendations for rice. Available online: https://ifdc.org/2022/07/25/Nepal-launches-site-specific-fertilizer-recommendations-for-rice/ (accessed on 2 June 2023).
11. Bana RC, Yadav SS, Shivran AC, et al. Site-specific Nutrient Management for Enhancing Crop Productivity. International Research Journal of Pure and Applied Chemistry. 2020, 21(15): 17-25. doi: 10.9734/irjpac/2020/v21i1530249
12. Buresh RJ. Site-specific nutrient management in rice. In: Proceedings of the International Potash Institute (IPI), and World Phosphate Institute (IMPHOS); 8 February 2007; Sharm El-Sheik, Egypt.
13. Havlin JL, Tisdale SL, Nelson WL, Beaton JD. Soil Fertility and Fertilizers an introduction to Nutrient Management, 8th ed. Pearson India Education; 2017.
14. Dinkins CP, Jones C. Interpretation of Soil Test Reports for Agriculture, Extension. Montana State University; 2013.
15. Pandit NR, Choudhary D, Maharjan S, et al. Optimum Rate and Deep Placement of Nitrogen Fertilizer Improves Nitrogen Use Efficiency and Tomato Yield in Nepal. Soil Systems. 2022, 6(3): 72. doi: 10.3390/soilsystems6030072
16. Rawal N, Pande KR, Shrestha R, et al. Soil Nutrient Balance and Soil Fertility Status under the Influence of Fertilization in Maize-Wheat Cropping System in Nepal. Applied and Environmental Soil Science. 2022, 2022: 1-11. doi: 10.1155/2022/2607468

17. Soil Management Directorate. Annual Report 2013–2014. Soil Management Directorate, Department of Agriculture, Hariharbhawan; 2014.
18. Tandan RP, Rai R, Basnet L, Karki KB. Soil nutrition distribution in Eastern Tarai of Nepal: A case study of Jhorahat VDC of Morang District. In: Proceedings of the Second National Soil Fertility Research Workshop; 24–25 March 2015; Kathmandu, Nepal.
19. Grzyb A, Wolna-Maruwka A, Niewiadomska A. Environmental Factors Affecting the Mineralization of Crop Residues. Agronomy. 2020, 10(12): 1951. doi: 10.3390/agronomy10121951
20. Dahal H. Research Perspective on Nutrient Management and Sustainability of Agriculture. Online Published Book; 2021.
21. Verma VK, Patel LB, Toor GS, Sharma PK. Spatial distribution of macronutrients in soils of arid tract of Punjab, India. International Journal of Agriculture and Biology. 2005, 7(2).
22. Tiwari KR. Soil types and fertility status in Western Terai Region of Nepal: A case from the Bankatawa VDC of the Banke District. In: Proceedings of the Second National Soil Fertality Research Workshop; 24–25 March 2015; Lalitpur, Nepal.
23. Schmidt O, Hughes-Games G. Potassium Considerations for Nutrient Management. Nutrient Management Factsheet No 7. Ministry of Agriculture and Lands; 2010.
24. Qureshi A, Singh DK, Pandey PC, et al. Site specific nutrient management approach for enhancing productivity and profitability in rice and wheat under rice-wheat cropping system. International Journal of Agricultural Sciences. 2016, 8(54): 2838–2842.
25. Verma P, Chauhan A, Ladon T. Site specific nutrient management: A review. Journal of Pharmacognosy and Phytochemistry. 2020, 9(5): 233–236.
26. Chivenge P, Zingore S, Ezui KS, et al. Progress in research on site-specific nutrient management for smallholder farmers in sub-Saharan Africa. Field Crops Research. 2022, 281: 108503. doi: 10.1016/j.fcr.2022.108503
27. Richards MB, Bahl KB, Jat ML, et al. Site Specific Nutrient Management: Implementation Guidance for Policy Makers and Investors. Global Alliance for Climate Smart Agriculture; 2015.
28. Cotteni A. Soil and Plant Testing as A Basis of Fertilizer Recommendations. FAO Soil Bulletin 38/2; 1980.
29. Sanchez PA. Properties and Management of Soils in the Tropics. John Wily and Sons; 1976.
30. Pierce FJ, Robert PC, Mangold G. Site specific management: The pros, the cons, and the realities. Available online: https://dr.lib.iastate.edu/server/api/core/bitstreams/353dabfa-f415-44c5-8049-37787740fc15/content (accessed on 20 February 2024).
31. Sida TS, Gameda S, Chamberlin J, et al. Failure to scale in digital agronomy: An analysis of site-specific nutrient management decision-support tools in developing countries. Computers and Electronics in Agriculture. 2023, 212: 108060. doi: 10.1016/j.compag.2023.108060
32. Betteridge K, Schnug E, Haneklaus. Will site specific nutrient management live up to expectation? Agriculture and Forestry Research. 2008, 2008(58): 283-294.

Appendix

Table A1. Variables affecting rice yield in the study area.

N **(%)**	***P*** **(kg/ha)**	***K*** **(kg/ha)**	**Fertilizer nutrient (kg/ha)**	**Irrigation (area %)**	**Rice yield (kg/ha)**
0.11	106.00	256.00	43.00	37.00	3060.00
0.11	94.00	103.00	36.00	42.00	3080.00
0.12	337.00	383.00	38.00	67.00	3600.00
0.10	219.00	398.00	32.00	37.00	2570.00
0.10	62.00	300.00	35.00	40.00	2750.00
0.12	155.00	427.00	40.00	60.00	3460.00
0.08	170.00	197.00	26.00	31.00	2050.00
0.10	71.00	308.00	30.00	37.00	2600.00

Table A2. Correlation coefficient interpretation.

Range	**Interpretation**
0.00 to 0.10	Negligible
0.10 to 0.39	Weak
0.40 to 0.69	Moderate
0.70 to 0.89	High
0.90 to 1.00	Very high

Source: Correlation coefficients: Appropriate use and interpretation (Anesthesia and Analgesia 126(5): 1763–1768, May 2018).