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# Site-specific nutrient management improves soil quality in an ultisol under continuous cassava cultivation

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## Abstract

The study aimed to assess the impact of fertilizer applications on soil properties and compute soil quality index (SQI) in a laterite soil under cassava cultivation. The treatments comprised N omission, P omission, K omission, NPK omission, present recommendation (PR) and site-specific nutrient management (SSNM). Soil physico-chemical and biochemical properties were estimated and, selected minimum data set through principal component analysis and soil quality index were developed. Radar diagram was plotted to find out the limiting parameter and correlation between SQI and crop yield was studied. Soil properties such as pH, organic C, labile C, available N, P, K, Ca, Mg, Fe, Mn and Zn showed significant difference among the treatments. SSNM resulted in significantly higher pH (4.60), labile carbon (0.143%), available N (214.82 kg ha$^{-1}$), Ca (119.70 ppm), Mg (156.15 ppm), Fe (10.20 ppm) and Zn (13.51 ppm) contents. PR treatment showed significantly higher content of organic C (1.17%) and available P (248.44 kg ha$^{-1}$). Available K and Mn were significantly higher in N omission (472.92 kg ha$^{-1}$) and NPK (47.80 ppm) omission treatment respectively. Normalised SQI was significantly highest for SSNM (0.86), followed by PR (0.73) and lowest for N omission (0.54), followed by P omission (0.55). No significant correlation was observed between crop yield and SQI. The study indicated that SSNM resulted in improvement of soil quality as revealed from higher SQI.

**Keywords:** Cassava, site-specific nutrient management, soil quality index, crop yield

## Introduction

Cassava (*Manihot esculenta* Crantz), a dicotyledonous perennial shrub belonging to the family Euphorbiaceae and a major food, animal feed and industrial crop of Africa, Asia, and Latin America, grows well in the latitudinal region of 30° north and south of the equator. It grows well in regions where annual rainfall, annual temperature and mean solar radiation is more than 1000 mm, 18°C and 16 MJ m$^{-2}$ respectively (Byju et al., 2015). Cassava is well adapted in diverse types of soil and it produces high yields under good crop management in fertile soil. The crop grows well in drained laterite, gravelly and sandy loams soils, while sandy, sandy loam and clay loam are the soil textural types that favour tuber development and easy harvest (Jose, 2002). For cassava the optimum soil pH is 5.5 and the crop is highly acclimatized to higher acidity ranging from pH 3.7-4.3 (Chew et al., 1981). Cassava is able to yield about 5-6 t ha$^{-1}$ under poor soil conditions (Cock and Howeler, 1978). At soil temperature ranging from 28-30°C, rapid germination and establishment from stem cutting is noticed, whereas below 17°C or above 37°C sprouting ceases (Keating and Evenson, 1979).

Soil has tremendous capacity to support life through its dynamic functions. It forms the basis of terrestrial life and is an important sink of atmospheric carbon

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dioxide. Unscientific and careless management of soil has resulted in deterioration in quality especially in agricultural lands and industrial areas. So, it is inevitable that the dynamic process of soil management has to be handled with a holistic approach combining the knowledge of all the sciences, depending upon the nature of problems (Verchot et al., 2007). Soil quality in relation to agricultural productivity and sustainability is a growing topic of interest. The fact is that the high yielding varieties and diverse crops intended for increased food production cannot overcome the problems of poor soil quality. So, there is a requirement to develop methodologies that promotes the assessment of soil quality in a region.

There exist different methods of conventional fertilizer management approaches for cassava. Conventional fertilizer management approaches such as blanket recommendations result in lower fertilizer use efficiency, imbalanced NPK applications and thereby deterioration in soil quality (Byju et al., 2016). One of the most promising approaches is site specific nutrient management (SSNM), which is dynamic, and it considers both plant and soil together, the two sides of a coin, and thus both are benefitted. The approach aims at nutrient applications at optimal rates and times for achieving more profits with increased nutrient use efficiency of the crops across time and space; thereby avoiding nutrient loss to the environment. In India, SSNM technology was developed and validated for cassava cultivation based on the modified QUEFTS (Quantitative Evaluation of the Fertility of Tropical Soils) model and was found to increase the yield of cassava by 22 per cent on average (Byju and Suja, 2020).

## Materials and Methods

### Study site and experimental description

The study site was a 10 year continuous SSNM experimental field in the Research Farm of ICAR-Central Tuber Crops Research Institute (ICAR-CTCRI) Thiruvananthapuram, Kerala, India (8°32’N latitude and 76°55’ E longitude, 50 m above MSL). The on-station experiment was started during 2008 and the present study was conducted during 2017-18. The temperature experienced during the crop period (7 months) ranged from 24.03°C to 31.42°C and rainfall 1313.5 mm. The soil in the plot is classed as clayey, skeletal, isohyperthermic, typic, plinthustults. The average initial nutrient status of SSNM and PR plots showed pH-4.56 and 4.63, OC-1.0 and 1.13%, available N-153.27 and 141.51 kg ha$^{-1}$, available P-89.18 and 77.89 kg ha$^{-1}$ and exchangeable K-112.11 and 141.51 kg ha$^{-1}$ respectively.

The experimental design was a randomised complete block design (RCBD) with six treatments and four replications. A short duration (6 months) variety of cassava, Sree Vijaya, characterised with tuber having very good cooking quality was the test variety. The recorded tuber yield of Sree Vijaya was 25-28 t ha$^{-1}$, and the starch content was 27-30%. The tuber flesh is yellow colour showing the presence of carotene. The treatments included for the study were nitrogen omission plot (0N), phosphorus omission plot (0P), potassium omission plot (0K), nitrogen, phosphorus and potassium omission plot (0NPK), present recommendation plot (PR) and site-specific nutrient management plot (SSNM). All other crop management practices were done uniformly as per Nair et al., (2004). Details about the soil treatment is shown in Table 1.

Table 1. Details of different soil treatments

| Nutrient (kg ha$^{-1}$) | Treatment | | | | | |
|---|---|---|---|---|---|---|
| | 0N | 0P | 0K | 0NPK | PR | SSNM |
| N | 0 | 150 | 150 | 0 | 100 | Customised fertilizer developed for agro ecological unit (AEU) 8 of Kerala, which includes secondary (Ca, Mg) and micronutrients (Fe, Mn, Zn, Cu), (Byju et al., 2016). |
| $P_2O_5$ | 75 | 0 | 75 | 0 | 50 | |
| $K_2O$ | 150 | 150 | 0 | 0 | 100 | |

### Soil sampling and analysis

The soil samples were collected at the time of harvest for estimation of physico-chemical and biochemical properties. From each treatment, representative soil samples were collected. A portion of the sampled soil were air dried and sieved using a 2 mm sieve before various physico-chemical analysis. Remaining portion were used fresh on the same day for soil enzyme studies. The methods adopted for the various soil analysis is shown in the Table 2.

Table 2. Methods used for physico-chemical and enzyme analyses of soil

| Parameter | Method | Reference |
|---|---|---|
| Soil physical properties | | |
| Single value constants | Keen Raczkowskii box method | Wright, 1939 |
| Texture | Hydrometer method | Bouyoucos, 1927 |
| Turbidity ratio | Turbidimetric method | Williams et al., 1966 |

| | | |
|---|---|---|
| Soil chemical properties | | |
| pH | 1:2.5 soil: water suspension, pH meter | Page et al., 1982 |
| Organic carbon | Chromic acid digestion method | Walkley and Black, 1934 |
| Labile carbon | Permanganate method | Weil et al., 2003 |
| Available nitrogen | Micro diffusion method | Janaki and Thyagarajan, 2001 |
| Available phosphorus | Bray and Kurtz No. 1 method, Spectrophotometer | Bray and Kurtz, 1945 |
| Exchangeable potassium | Neutral 1N ammonium acetate, Flame Photometer | Page et al., 1982 |
| Available calcium, magnesium | Neutral 1N ammonium acetate, Atomic absorption spectrophotometer | Page et al., 1982 |
| Available sulfur | 0.15% $CaCl_2$, Spectrophotometer | Williams and Steinbergs, 1964 |
| Available Fe, Mn, Zn, Cu | Extraction using 0.1 M HCl, Atomic absorption spectrophotometer | Osiname et al., 1973 |
| Available boron | Extraction using hot water, Azomethine-H method | Gupta, 1967 |
| Soil enzymes | | |
| Urease | Colorimetric estimation of urea | Broadbent et al., 1958 |
| Dehydrogenase | TTC assay | Casida et al., 1964 |
| Phosphatase | Colorimetric estimation of p–nitrophenol | Tabatabi and Bremner, 1969 |

**Statistical analysis**

The experimental data obtained were subjected to the analysis of RCBD and the data interpretation was based on Panse and Sukhatme (1985). At a 5% level of significance, analysis of variance (ANOVA) was used to examine the significance of mean values obtained across treatments. The principal component analysis (PCA) was performed using SSCNARS online portal (http://sscnars.icar.gov.in). The soil quality index (SQI) developed by Andrews et al., (2002), which performs very well for small-scale on farm studies was adopted for the study. The basic steps involved in the study were: (i) identification of significant parameters (ii) preparation of minimum data set (MDS) using PCA (iii) normalization of MDS indicators and (iv) indicator scores integration.

Based on results of ANOVA described earlier, all parameters with significant difference among treatments were selected for principal component analysis (PCA). To filter the most suitable indicators for minimum data set (MDS) the data reduction technique PCA was used (Armenise et al., 2013). In the present study, PCA was performed for 11 soil parameters, which were significantly different. The result obtained from the PCA gives a new set of variables 'Principal Components' (PCs). The first principal component (PC) accounts for most of the remaining variability. Eigen value from the PCA depicts the approximate contribution of PC to the total variance (Armenise et al., 2013). Minimization of the indicators was performed on the basis of eigen-one criterion or Kaiser criterion (Kaiser, 1960) and PC that explains at least 10 per cent of the variance in data were included. According to eigen-one criterion, it is considered that PC1 receiving high eigen values gives best representation of the system and therefore only the PCs with eigen values greater than 1 will be selected.

A weight or factor loading was given to each soil property under certain PC to represent the contribution of the variable to the composition of PC. Only the most highly weighted factors were retained for MDS under each PC. Factor loadings with absolute values less than 10 per cent of the highest factor loading were considered highly weighted (Wander and Bollero, 1999).

To transform the MDS soil properties, linear scoring functions were used, by considering the site-specific characteristics (Table 2). 'More is better function' was used for the all the properties (Liebig et al., 2001; Mukherjee and Lal, 2014). As all soil characteristics of the treatments were below the sufficient level (suggested by ICAR-National Bureau of Soil Survey and Land Use Planning), the score was calculated by dividing each value by the highest value in a particular parameter. All the values of the MDS indicators were transformed to linear functions, where the y-axis ranges from 0 to 1, while the x-axis depicts a site-dependent range (Karlen and Stott, 1994; Andrews and Carroll, 2001). The score 1 was given for highest indicator value. Based on the PCA results, weighted factors were allocated (Table 6). Weights for designated variables were calculated by percent variance in the dataset explained by the selected PCs (Masto et al., 2008). For an indicator in particular PC, full weights was assigned to the indicator.

Table 2. The linear scoring equations used to transform the measured indicator values into scores

| Indicator | Equation |
|---|---|
| Soil pH | $y = 0.2083\times$ |
| Available N | $y = 0.004\times$ |
| Available P | $y = 0.0037\times$ |
| Available Ca | $y = 0.008\times$ |
| Available Mn | $y = 0.0202\times$ |
| Available Zn | $y = 0.0614\times$ |

The percent variance in the dataset explained by the selected PCs was used to generate weights for selected variables (Masto et al., 2007). Indicator integration into indices was performed using the unscreened transformation using equation (1)

$$\text{Normalized SQI} = \sum_{i=1}^{n} Si/n \qquad (1)$$

where 'Si' denotes linear scores of observed soil quality indicator, 'n' the number of indicators used in the index.

The final PCA based soil quality equation is

$$\text{SQI} = \sum_{i=1}^{n} Wi/Si \qquad (2)$$

Where 'W' is the PC weighting factor and 'S' is the indicator score.

The normalized SQI was finally calculated to limit the SQI values in the range 0 to 1. The higher the index score, the better the soil quality or the better the soil function. For each treatment, the per cent contribution of each selected indicator to the total SQI was determined. Limiting soil parameter among the selected indicators was identified using radar diagram and the effect of treatments in crop yield was also assessed. The overall step in the process of development of soil quality index is shown in Fig. 1.

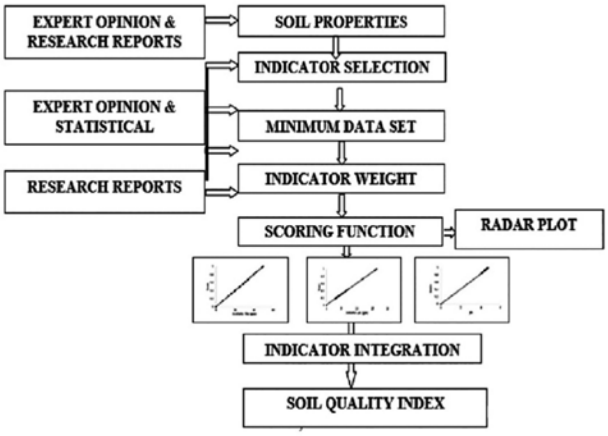

Fig. 1. Steps involved in development of soil quality index (SQI) (modified after Masto et al., 2007)

## Results and Discussion

### Soil physico-chemical properties and enzyme activities

The effects of different treatments on soil physical properties are presented in Table 3. The physical properties did not show any significant difference among the six treatments. Though not significant, highest bulk density was recorded in N omission treatment (1.29 Mg $m^{-3}$) and lowest for present recommendation (PR) (1.22 Mg $m^{-3}$), closely followed by site specific nutrient management (SSNM) (1.23 Mg $m^{-3}$). A slight improvement in water holding capacity was recorded in SSNM (40.99%) and PR (40.84%) treatments compared to nutrient omission treatments. Highest values of porosity (55.82%) and turbidity ratio (0.46%) were recorded in SSNM treatment.

Stockdale et al., (2001) reported that it took decades to establish quantifiable changes in soil physical properties. Slight changes in soil physical properties under organic farming was reported by Suja et al., (2012). Similar results was also reported by Madhavi et al., (2020) in cassava cultivated soils.

The effect of different treatments on soil chemical properties is shown in Table 4. A significantly higher pH was observed in SSNM treatment (4.60), which was on par with PR (4.57), N omission (4.55) and K omission (4.46) treatments. Significantly lower pH was observed in P omission treatment (4.14). The organic carbon was significantly higher for PR (1.17%) treatment, followed by SSNM (1.15%) and P omission (1.06%) treatment. Significantly lower OC content was recorded in K omission and NPK omission treatments (0.82%). Significantly higher labile carbon content was found in SSNM treatment (0.14349), which was on par with P omission (0.14347%) and PR treatments (0.14346%), while significantly lower labile carbon was recorded in N omission (0.14333%), followed by NPK omission (0.14335%) treatments. Significantly higher available N content was observed in SSNM treatment (214.82 kg $ha^{-1}$), which was on par with PR treatment (192.08 kg $ha^{-1}$). Significantly lowest available N content was observed in N omission treatment (126.22 kg $ha^{-1}$), followed by NPK omission treatment (133.67 kg $ha^{-1}$). Available P content was significantly higher in PR treatment (248.44 kg $ha^{-1}$), followed by SSNM (242.47 kg $ha^{-1}$) and was significantly lower in N omission (160.62 kg $ha^{-1}$), P omission (169.61 kg $ha^{-1}$) and K omission (105.06 kg $ha^{-1}$) treatments. Available K content was significantly higher in N omission treatment (472.92 kg $ha^{-1}$), while it was significantly lower in K omission treatment (105.06 kg $ha^{-1}$), followed by NPK omission treatment (148.90 kg $ha^{-1}$).

Among the secondary nutrients, Ca and Mg showed significant difference among the treatments. A

Table 3. Effect of treatments on physical properties of soil

| Treatments | Sand | Silt | Clay | BD* | WHC* | Porosity | TR* |
|---|---|---|---|---|---|---|---|
| | % | % | % | Mg m$^{-3}$ | % | % | - |
| N omission | 73.93 | 1.60 | 24.48 | 1.29 | 39.83 | 54.51 | 0.14 |
| P omission | 73.55 | 1.85 | 24.60 | 1.26 | 39.56 | 52.41 | 0.18 |
| K omission | 73.55 | 1.78 | 24.67 | 1.27 | 38.48 | 52.83 | 0.13 |
| NPK omission | 73.93 | 1.38 | 24.70 | 1.24 | 39.97 | 51.52 | 0.35 |
| PR | 74.05 | 1.73 | 24.23 | 1.22 | 40.84 | 52.63 | 0.26 |
| SSNM | 73.92 | 1.78 | 24.30 | 1.23 | 40.99 | 55.82 | 0.46 |
| LSD (0.05) | NS | NS | NS | NS | NS | NS | NS |

*BD- bulk density (Mg m$^{-3}$), WHC- water holding capacity in (%), TR- turbidity ratio

Table 4. Effect of treatments on chemical properties of soil

| Treat-ments | pH | OC* | LC* | Available N kg ha$^{-1}$ | Available P | Exchange-able K | Available Ca | Available Mg | Available S | Available Fe | Available Mn | Available Zn | Available Cu | Available B |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | % | % | | kg ha$^{-1}$ | kg ha$^{-1}$ | mg kg$^{-1}$ | mg kg$^{-1}$ | mg kg$^{-1}$ | mg kg$^{-1}$ | mg kg$^{-1}$ | mg kg$^{-1}$ | mg kg$^{-1}$ | mg kg$^{-1}$ |
| 0N | 4.55 | 0.86 | 0.14333 | 126.22 | 160.62 | 472.92 | 88.80 | 33.80 | 15.19 | 7.50 | 22.75 | 3.66 | 1.55 | 0.97 |
| 0P | 4.14 | 1.06 | 0.14347 | 146.61 | 164.71 | 286.83 | 67.20 | 22.33 | 8.91 | 8.62 | 33.62 | 4.59 | 1.79 | 0.80 |
| 0K | 4.46 | 0.82 | 0.14338 | 163.07 | 169.91 | 105.06 | 92.30 | 29.75 | 14.49 | 6.80 | 21.76 | 4.55 | 1.62 | 0.66 |
| 0NPK | 4.35 | 0.82 | 0.14335 | 133.67 | 199.22 | 148.90 | 90.40 | 40.60 | 19.84 | 8.48 | 47.80 | 4.31 | 1.78 | 0.70 |
| PR | 4.57 | 1.17 | 0.14346 | 192.08 | 248.44 | 387.74 | 111.40 | 99.00 | 20.08 | 10.06 | 21.38 | 6.74 | 1.73 | 0.72 |
| SSNM | 4.60 | 1.15 | 0.14349 | 214.82 | 242.47 | 395.02 | 119.70 | 156.15 | 18.21 | 10.20 | 30.22 | 13.51 | 1.90 | 1.26 |
| CD (0.05) | 0.24 | 0.215 | 0.0001 | 45.522 | 26.15 | 74.92 | 15.20 | 68.771 | NS | 1.41 | 12.832 | 2.04 | NS | NS |

*OC - organic carbon, LC - labile carbon

significantly higher available Ca content was observed in SSNM treatment (119.7 ppm), followed by PR treatment (111.4 ppm), while significantly lower Ca content was recorded in P omission treatment (67.20 ppm). The SSNM treatment showed significantly higher Mg content (156.15 ppm) and P omission showed significantly lower Mg (22.33 ppm). which was on par with K omission treatment (29.75 ppm). Among the micronutrients, Fe, Mn and Zn showed significant variation among the treatments. A significantly higher available Fe was observed in SSNM treatment (10.20 ppm), which was on par with PR (10.06 ppm) and significantly lower Fe content in K omission treatment (6.80 ppm). Available Mn was significantly higher in NPK omission (47.80 ppm) while it was significantly lower in PR (21.38 ppm), which was on par with N (22.75 ppm), P (33.62 ppm), K (21.76 ppm) omission and SSNM (21.38 ppm) treatments. The SSNM treatment (13.51 ppm) showed significantly higher available Zn, while N omission treatment showed significantly lower values and was on par with P (4.59 ppm), K (4.55 ppm) and NPK (4.31 ppm) omission treatments.

Apart from NPK, addition of farmyard manure and litter fall in SSNM and PR plots have contributed to significant increase in the OC and NPK content. Further in SSNM treatment secondary nutrients such as Ca and Mg, and micronutrients Fe, Mn, Zn and Cu were applied along with customized formulation. This is the reason for significant increase in these nutrients in SSNM treated soil than others. Similar result was reported by Madahavi et al., (2020).

The results of soil enzyme activities are presented in Table 5. No significant differences in soil enzyme activities could be observed. The value of urease activity was highest in SSNM (1473.31 $\mu$g g$^{-1}$ h$^{-1}$) and lowest in K omission (1138.12 $\mu$g g$^{-1}$ h$^{-1}$). The value of phosphatase was highest in PR (302.21 $\mu$g PNP g$^{-1}$ h$^{-1}$) and lowest in P omission (203.69 $\mu$g PNP g$^{-1}$ h$^{-1}$). The highest and lowest value of dehydrogenase were observed in NPK omission treatment (27.85 $\mu$g TPF g$^{-1}$ h$^{-1}$) and SSNM treatment respectively. As there are no organic treatments no significant increase in enzyme activity was noticed in the soil of any treatments.

Table 5. Effects of treatments on soil enzyme activities

| Treatments | Urease | Dehydrogenase | Phosphatase |
|---|---|---|---|
| | $\mu$g g$^{-1}$ h$^{-1}$ | $\mu$g TPF g$^{-1}$ h$^{-1}$ | $\mu$g PNP g$^{-1}$ h$^{-1}$ |
| N omission | 1288.55 | 21.22 | 248.72 |
| P omission | 1139.42 | 20.79 | 203.69 |
| K omission | 1138.12 | 18.47 | 244.49 |
| NPK omission | 1177.69 | 27.85 | 251.14 |
| SSNM | 1473.31 | 15.98 | 259.90 |
| PR | 1359.81 | 27.59 | 302.21 |
| LSD (0.05) | NS | NS | NS |

**Principal component analysis (PCA)**

Soil quality index (SQI) was computed to evaluate the effect of different treatments on soil quality. For the principal component analysis (PCA), the soil parameters that showed significant difference among the treatments were selected. By taking into account the aforementioned soil characteristics, 11 PCs were generated using the principal component analysis (Table 6).

Table 6. Results of principal component analysis of soil quality indicators for the first three PCs selected for computing SQI

| Principal Components | PC 1 | PC 2 | PC 3 |
|---|---|---|---|
| Eigen value | 5.15 | 1.55 | 1.40 |
| Loading factor | 0.64 | 0.19 | 0.17 |
| Per cent | 46.84 | 14.11 | 12.72 |
| Cumulative percent | 46.84 | 60.95 | 73.66 |
| Eigen vectors | | | |
| pH | 0.219 | -0.562 | 0.342 |
| OC | 0.300 | 0.201 | -0.397 |
| LC | 0.243 | 0.183 | -0.569 |
| N | 0.373 | -0.079 | -0.926 |
| P | 0.364 | 0.193 | 0.248 |
| K | 0.211 | -0.336 | -0.161 |
| Ca | 0.346 | -0.016 | 0.359 |
| Mg | 0.327 | 0.183 | 0.184 |
| Fe | 0.335 | 0.128 | -0.008 |
| Mn | -0.644 | 0.635 | 0.378 |
| Zn | 0.380 | -0.022 | 0.009 |

With reference to Kasier (1960) criterion, the number of datasets that can be included was limited up to PC3, as from PC4 onwards the eigen value dropped below 1. The three PCs together contributed 73.67% of the total variance, while the residual components only marginal. The percentage explained by PC1, PC2 and PC3 are 46.84, 14.11 and 12.72% respectively of the total variance. In PC1, Mn showed very high value, which is double than that of other eigen vectors and so it was considered in PC2. Thus in PC1, Zn, P and N were the highest weighed variables, while for PC2 they were Mn and soil pH. Though N showed very highly weighed variable in PC3 it was not considered as it was already considered in PC1. Considering the rest of eigen values, LC showed highest value but the critical difference among the treatments was very low and so it was not considered. As Mn was considered in PC2 it was discarded. Thus, in PC3 highest weighed variable considered was Ca. Therefore, the final dataset contains only 6 variables, namely pH, N, P, Ca, Mn and Zn.

**Soil quality index (SQI)**

The final equation for normalised PCA based soil quality is:

$$\text{Normalised SQI} = 0.636\ [(SN+SP+SZn)/3] + 0.192\ [(SpH+SMn)/2] + 0.173\ (SCa/1)$$

Fig. 2 and Table 7 shows normalised cumulative soil quality indices for the various treatments.

The contribution of the MDS indicators (scored and weighed) to the overall index value is represented by the bars.

Table 7. Normalised cumulative soil quality indices for different treatments

| Treatments | Normalised SQI |
|---|---|
| N omission | 0.54 |
| P omission | 0.55 |
| K omission | 0.59 |
| NPK omission | 0.63 |
| PR | 0.73 |
| SSNM | 0.86 |
| LSD | 0.094 |

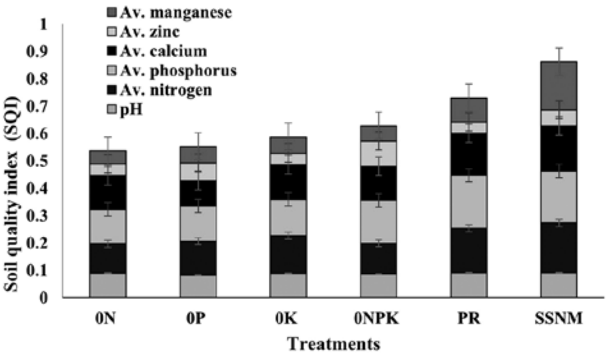

Fig. 2. Effect of different fertilizer treatments on soil quality index (SQI)

Significant differences between the treatments were showed in the normalised cumulative SQI values by the various treatments. The SSNM treatment (0.86) showed significantly higher soil quality index, which was followed by PR treatment (0.73) and significantly lower SQI was shown by N omission treatment (0.54), followed by P omission treatment (0.55). The soil parameters that have contributed to the increase in SQI in SSNM are available N, P, Ca and Mn. Madhavi et al., (2020) has reported an increase in SQI in SSNM treated soil under cassava.

### Correlation of soil quality index and tuber yield

The yield of a crop depends on environmental, biological and technological factors. Improvement in SQI contributes to the availability of essential nutrients to the crop. But in this study no linear correlation was found between crop yield and SQI indicating that the factors that are not considered in the study have also contributed to the tuber yield (Fig. 3). This result is in tune with Armenise et al., (2013), which states that 'these were either not soil related or due to 'patchy' spatial variation of soil quality in the field'.

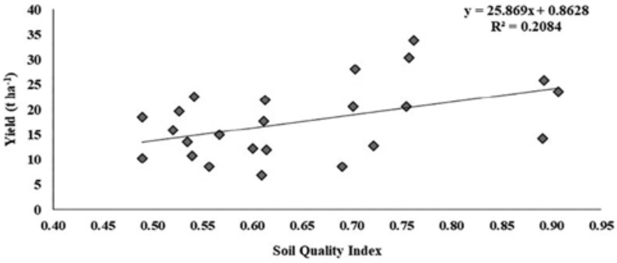

Fig. 3. Correlation of soil quality index (SQI) values and tuber yield

## Conclusion

The study has contributed for evaluating the impact of different treatments on soil quality. The study indicates that application of SSNM for ten years has not imparted a significant effect on physical and enzyme activities of the soil, but on chemical parameters. No correlation was noticed between SQI and tuber yield, indicating that the indicators selected for the SQI are not the only factors that contributes to yield but is a combination of various climatic and edaphic factors. Thus, it can be concluded that continuous application of SSNM for 10 yrs has improved soil quality.

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