# Soybean Yield Determinants and Response to Rhizobial Inoculation in an On-farm Trial in the Northern Guinea Savanna of Nigeria

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## Abstract

The response of two soybean varieties (Samsoy-2 and improved variety TGx 1448-2E) to *Bradyrhizobium* inoculation in the northern Guinea savanna of Nigeria was tested in a researcher-managed on-farm trial. There were variations in soybean yields between and within farmers' fields. Data obtained from 24 farmers' fields were analysed in a mixed model analysis of variance whereby the variance of the random component was estimated using Gausian restricted maximum likelihood. Five major soil components recognised to contribute to the yield determining factors of the soybean varieties were as follows: (a) effective cation exchange capacity (ECEC), (b) silt and phosphorus, (c) acidity (d) soil total nitrogen and (e) salinity. The coefficient of determination in a stepwise regression analysis gave ($R^2$) up to 0.23 ECEC > silt and phosphorus > acidity > total nitrogen > salinity. Thus, some acceptable levels of cations in the soil are necessary for soybean establishment and BNF in farmers' fields. Inoculation of the Samsoy-2 variety did not have significant effect on the vegetative parameters (shoot, root, nodule number and shoot and nodule fresh weight) measured. This showed that the native rhizobial population was adequate for soybean nodulation. However, significant effect of the inoculated strain was observed only in the root biomass of the improved variety. While inoculation of the Samsoy-2 did not have significant effect on biological nitrogen fixation (BNF) and grain yield, the BNF and grain yield of the improved variety were significantly higher than the farmers' local variety showing that varietal differences masked the effect of inoculation.

## Introduction

Production of soybean is rapidly taking a centre place among cereals and grain legume productions in the moist savanna zone (MSZ) of Nigeria. This stems from the fact that it is rapidly becoming a major food as well as an industrial crop in Nigeria (Brader, 1998). The growth in area of cultivation and increase in the yield is due to the result of farmers' adoption of newly bred soybean varieties at the IITA. These varieties that store well, do not require expensive inputs such as high nitrogen fertilizer needed by maize or pesticides spraying on cowpea to sustain production.

These IITA high-yielding soybean varieties nodulate with the native rhizobia strains, thus to some extent the requirement for N is taken care of through biological nitrogen fixation (BNF) once the plants are established. The promiscuous soybean cultivar (TGx 1448-2E) released by IITA out-yields the farmer variety (Samsoy-2) by over one tonne ha$^{-1}$ is preferred due to its high vegetative biomass, good groundcover to reduce weed, high $N_2$-fixation and low-level soil P tolerance. The soybean cultivar which also fixes up to 70% of its required N, has a positive N-balance in the soil as residual N (14–18 kg N ha$^{-1}$) for the following soybean crop or cereal in crop rotation practice (Sanginga *et al.*, 1997). Soybean grows well in soil of pH 6.0 or higher, but can also tolerate a pH of 4.3–4.8. Available phosphorus levels critical for soybean production ranges between 10 and 15 mg kg$^{-1}$ soil (Aune and Lal, 1997).

In an on-farm trial involving 24 selected farmers in the IITA benchmark site (Kaya near Zaria) in the northern Guinea savanna of the moist savanna zone (MSZ) of Nigeria, variations were observed in the yield of TGx 1448-2E, and the local farmer varieties, despite uniform management practices in the researcher-managed fields. The soils of the site are classified as Alfisols and are texturally sandy loam in nature in most of the fields (Weber *et al.*, 1995c). Bradyrhizobia inoculation technology was introduced into the cropping system of the area and it was observed to have no significant effect on the grain yield of the soybean (Okogun and Sanginga, 2002). This showed that there are some fundamental factors that control soybean production apart from the similar management practice and their ability to fix nitrogen from the air. Thus this study was set up to investigate the factors responsible for the persistent variations in the yield of soybean in the farmers' fields with emphasis on soil properties.

## Materials and methods

This trial was conducted at IITA's benchmark site at Kaya village (7° 3'E, 11° 3'N) some 52 km north of Zaria in the northern Guinea savanna of the MSZ. Two broad groups of farmers were involved in this study; farmers who applied more than 30 kg N ha$^{-1}$ to their crops and farmers who applied less than this amount. Each of the two groups was further classified into farmers that practice removal of crop residues from fields at the end of each cropping season and those that retain residues. All together, 24 farmers were involved.

### Land preparation

All the farmers used animal traction in ridging the experimental fields after "knocking" down the old ridges with hand hoes. The ridges were spaced approximately 0.75 m between rows. Each plot for each treatment was 12 m × 12 m.

### Seed treatment and planting

Two varieties of soybean were planted in all the farmers' fields. These were farmer variety (Samsoy-2) and the introduced improved variety TGx 1448-2E. Both soybean varieties (farmer varieties and TGx 1448-2E) were surface sterilized as reported by Vincent (1970). Soybean seeds were inoculated with a mixture of R25B and IRj 2180A rhizobial strains using the method of Somasegaran and Hoben (1994).

Soybean seeds were drilled in to open grooves on the ridges and covered lightly with soil. The uninoculated soybean treatments were planted before to avoid contamination by the inoculated ones. The seeds were thinned to one plant per hill at 10 cm within row spacing two weeks after planting (WAP).

### Experimental design

This study was an on-farm trial in which 24 farmers' fields were involved and each farmer's field was a replicate. In each farm, there were experimental combinations of two soybean varieties (local and improved varieties) and two levels of inoculation (with and without inoculation). The agronomic practices for the soybean production were similar in all the farmers' fields. All the fields were not planted on the same day but the planting was completed within one week.

## Sampling

### Soil sampling

Before fields were prepared, two bulk soil samples were collected from each of the fields with a 6 cm soil auger at 0–15 cm, one sample from the ridges and one sample from the furrows of the previous cropping season. A subsample for physical and chemical analyses was taken from each bulk sample.

### Vegetative sampling: shoot, nodule, root, root bleeding, and nitrogen fixation

At 50% podding, 5 plants were randomly selected and cut at about 2 cm above soil level. The shoots were weighed fresh, later air dried for some days before finally oven drying at 70 °C for 72h.

The 5 plants were bled immediately after cutting in the field by fixing rubber tubing on the stumps. The sap was collected in glass vials. An about equal volume of alcohol was added to the sap that was kept on ice blocks in the cooler and later frozen in the laboratory until ready for analyses.

Nodules that became detached from the roots were carefully picked from the soil and brought to the laboratory. The roots were washed under running tap water in a 1 mm mesh. The nodules were separated from the roots, counted, and weighed.

About 1.0 g of the fine roots was collected in glass vials for staining for percentage root infection by arbuscular mycorrhizal fungi (AMF). The AMF infection was assessed using the method of Brundrett *et al.* (1984). Nitrogen fixation in soybean was measured using the method of Peoples *et al.* (1989).

### Grain yield

One hundred representative soybean plants were randomly harvested in each plot and the pods were removed and weighed fresh in the field. These were air dried, threshed, and oven dried at 70 °C to about 10% moisture. The data were used to estimate soybean yield.

## Statistical analysis

All the data were analyzed using SAS (1989) and the following models: mixed model analysis, and principal component analysis.

# Results

## Soil analysis

Most of the soils in the experimental area had pH ranging between 5 and 6.6 (Table 1); and the P ranged between 1.0 and 51.7 mg $kg^{-1}$ with a mean of 8.6 mg $kg^{-1}$. Out of the 24 fields, 75% had available P below the critical level of 10 mg $kg^{-1}$ soil while in field No. 3 the available P was highest (51 mg $kg^{-1}$) soil. Total N was low in most fields (0.045–0.075% and the ECEC ranged between 2.3 and 8.2 cmol $kg^{-1}$.

## Nodulation and %AMF root infection

The improved soybean variety (TGx 1448-2E) did not respond to inoculation in terms of nodule production. Varietal differences were very prominent. Thus, Samsoy-2 nodules were almost twice the nodules of the improved variety (Table 2). There were no significant differences in % AMF between the farmers' variety and the improved soybean variety.

## Shoot and root biomass, and grain yield

Inoculation with *Bradyrhizobium* had no significant effect on shoot and root dry matter yield of Samsoy-2. However, there was an insignificant increase of about 11%

TABLE 1
Chemical and physical characteristics of soils in 24 farmers' fields in Kaya, Zaria.

| Parameter | 0–15 cm depth | |
|---|---|---|
| | Ridge | Furrow |
| pH (water) | 5.67 | 5.31 |
| Total N (%) | 0.06 | 0.06 |
| Organic C (%) | 0.73 | 0.59 |
| Available P (mg/kg) | 8.57 | 6.92 |
| Exch. Bases(cmol/kg) | | |
| K | 0.26 | 0.38 |
| Mg | 0.71 | 1.00 |
| Ca | 2.25 | 2.72 |
| Mn | 0.04 | 0.02 |
| Na | 0.29 | 0.29 |
| ECEC | 3.93 | 4.94 |
| Exch. Acidity(cmol/kg) | 0.42 | 0.54 |
| Particle size (%) | | |
| Sand | 46.08 | 44.58 |
| Silt | 41.84 | 37.34 |
| Clay | 12.08 | 18.08 |

TABLE 2
Effects of soybean varieties on nodulation and percent arbuscle mycorrhizal fungi (AMF).

| Variety | Nodule No. (plant $^{-1}$) | Nodule weight* (g plant $^{-1}$) | AMF (%) |
|---|---|---|---|
| Samsoy 2 | 71.37 | 2.34 | 22.14 |
| TGx 1448-2E | 38.57 | 1.43 | 21.99 |
| S.E. | 8.0 | 0.2 | 1.0 |

* Nodule fresh weight.

in the shoot dry weight of TGx 1448-2E when inoculated. A significant increase was observed in the root dry matter yield of the inoculated improved soybean variety over the uninoculated improved variety (Fig 1). Varietal differences rather than rhizobial inoculation were responsible for the differences in the parameters observed. For instance, there was an increase in the grain yield of the introduced germplasm by about 1.2 t ha$^{-1}$ over the local Samsoy-2 variety.

## *Nitrogen fixation, shoot and grain N and P uptake*

Inoculation did not improve BNF in either the improved or the farmers' local varieties. Even though there were no significant differences between N and P uptake of Samsoy-2 and the

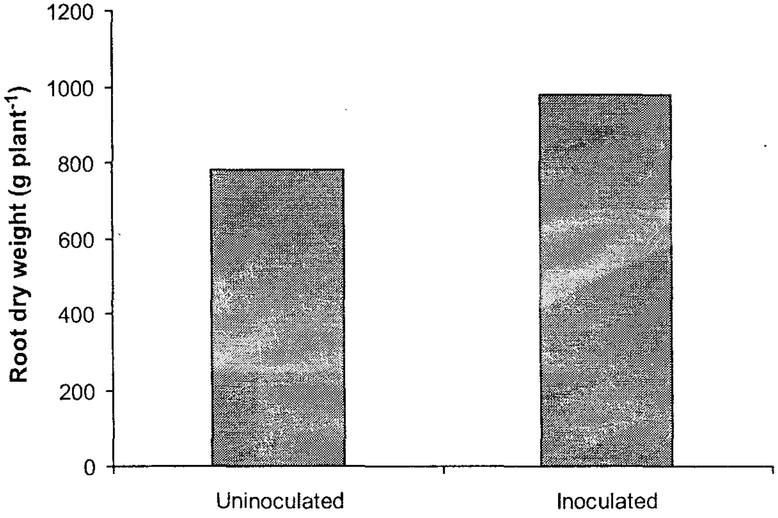

Figure 1: Effect of bradyrhizobia inoculation on root dry weight of TGx 1448-2E.

TABLE 3
Nitrogen and phosphorus uptake in shoot and grain of soybean varieties.

| | Nitrogen (kg ha $^{-1}$) | | Phosphorus (kg ha $^{-1}$) | |
|---|---|---|---|---|
| Variety | Shoot | Grain | Shoot | Grain |
| Samsoy 2 | 179 | 130 | 17 | 12 |
| TGx 1448-2E | 189 | 200 | 19 | 18 |
| S.E. | 16 | 18 | 3 | 2.0 |

improved variety in the shoots, the N content of the improved grain variety was 35% higher than in the local variety. The P content of the grain of the improved variety was 33% higher than in the local variety (Table 3).

## *Factors controlling grain "field mean" yield*

Response to treatments differed across fields. If the underlying conditions affecting mean field yield could be identified then it becomes possible to make recommendations to farmers and extrapolate to other villages in the NGS benchmark in the long run. Relationship among the variables (including the dependent variable) was investigated by correlation analysis based on Principal Component Analysis (PCA).

Ridge and furrow values of soil parameters given in Table 1 were the variables used in the principal component analysis giving a total of 28 variables (*P*) for 24 fields (n). Principal component analysis was used to summarize the data in order to evaluate the relationships among the variables and to extract the factors that may cause variability in the yield of soybean. The correlation matrix of the data

TABLE 4
Eigen values of the correlation matrix and the proportions of the variance to the total variance for derived principal components.

| Principal components (PC) | Eigen value | Proportion | Cumulative percentage |
|---|---|---|---|
| PC1 | 9.3047 | 0.3323 | 33.23 |
| PC2 | 5.4038 | 0.1930 | 52.23 |
| PC3 | 3.0711 | 0.1097 | 63.50 |
| PC4 | 2.3059 | 0.0824 | 71.73 |
| PC5 | 1.8067 | 0.0645 | 78.19 |
| PC6 | 1.1585 | 0.0414 | 82.32 |
| PC7 | 0.9975 | 0.0356 | 85.89 |
| PC8 | 0.8160 | 0.0291 | 88.80 |
| PC9 | 0.6811 | 0.0243 | 91.23 |
| PC10 | 0.5823 | 0.0208 | 94.90 |

was singular because the number of variables (P) was greater than the number of observations (n). Since the inverse matrix is not mathematically allowed when a correlation matrix is singular, the number of principal components (PC) derived from the analysis is not P-1, but n-1 (Kosaki *et al.,* 1989). Table 4 gives the eigen values of the correlation matrix. The first component explains 33% of the total variance. Since the first five principal components gave eigen values of 78.2 % of the total variance, other PCs were not considered but were viewed as errors. These included the random component of soil variation and various types of error produced in every stage of soil sampling and analysis (Kosaki and Juo, 1989). The factor pattern for the first five principal components is given in Table 5. The first component (factor) showed high positive correlation with Ca-furrow, Ca-ridge, Mg-furrow, Mg-ridge, K-ridge, ECEC-furrow, ECEC-ridge and clay-ridge and high negative correlation with sand-furrow. The base cations and ECEC correspond to the exchangeable base status and cation exchange capacity which are related to the original nature of the soil material formed under a specific environment and hence determine the potential chemical fertility of the soil (inherent fertility). Clay is relevant to the inherent potentiality of the soil. The high correlation of clay and sand refers to the texture of the soil. The first component (PC1) can thus be explained on the basis of the physicochemical properties of the soil (physicochemical factor). The second component (PC2) was highly correlated to P-furrow, silt-ridge, P-ridge, silt-furrow, K-furrow, Organic C-furrow and Total N-furrow. This component showed moderate correlation with Mn-ridge and acid-furrow. The pH-ridge was also moderately correlated with this component, but negatively. This component is

TABLE 5
Factor pattern for the first five principal components.

| Variable | PC1 | PC2 | PC3 | PC4 | PC5 |
|---|---|---|---|---|---|
| Ca-furrow | 0.87407 | -0.18299 | 0.00562 | 0.04097 | -0.22992 |
| Ca-ridge | 0.91711 | -0.15982 | 0.29042 | -0.04300 | 0.00845 |
| Mg-furrow | 0.89992 | -0.32205 | -0.14091 | -0.11928 | 0.03110 |
| Mg-ridge | 0.82303 | -0.43813 | 0.02947 | -0.09956 | 0.06080 |
| K-furrow | 0.36635 | 0.60985 | 0.40475 | 0.07474 | 0.29398 |
| K-ridge | 0.76455 | -0.17799 | 0.19838 | -0.22505 | 0.36540 |
| Na-furrow | 0.21650 | -0.07274 | 0.03366 | 0.13555 | 0.61532 |
| Na-ridge | 0.47203 | 0.12573 | -0.02962 | -0.45246 | 0.23729 |
| Mn-furrow | -0.30511 | 0.46575 | 0.13828 | -0.46612 | 0.44803 |
| Mn-ridge | -0.15531 | 0.57284 | 0.33758 | -0.51815 | 0.11784 |
| ECEC-Furrow | 0.93051 | 0.00807 | 0.16832 | 0.03308 | -0.16596 |
| ECEC-ridge | 0.93123 | -0.19031 | 0.24438 | -0.01025 | 0.02391 |
| Acid-furrow | 0.17683 | 0.56270 | 0.55758 | 0.08234 | -0.21450 |
| Acid-ridge | -0.00260 | 0.32743 | 0.14034 | 0.48151 | -0.07266 |
| P-furrow | 0.12001 | 0.72286 | 0.51769 | 0.11952 | 0.11051 |
| P-ridge | 0.30159 | 0.66259 | 0.58349 | 0.02487 | -0.00894 |
| pH-furrow | 0.05077 | 0.00670 | 0.64424 | 0.11806 | -0.49644 |
| pH-ridge | 0.56729 | -0.53232 | 0.37120 | 0.15403 | -0.14193 |
| Org.C-furrow | 0.22982 | 0.60695 | -0.28403 | 0.40184 | 0.27533 |
| Org.C-ridge | 0.66224 | 0.40156 | -0.29505 | 0.34253 | 0.04014 |
| Tot.N-furrow | 0.24031 | 0.60637 | -0.30884 | 0.57340 | 0.04595 |
| Tot.N-ridge | 0.60455 | 0.41711 | -0.40722 | 0.34049 | 0.15442 |
| Sand-furrow | -0.75116 | -0.25651 | 0.31022 | 0.14557 | 0.30173 |
| Sand-ridge | -0.53993 | -0.48461 | 0.44579 | 0.41630 | 0.12657 |
| Silt-furrow | 0.30167 | 0.60665 | -0.20374 | -0.32132 | -0.43064 |
| Silt-ridge | 0.14548 | 0.67599 | -0.49830 | -0.32813 | -0.27111 |
| Clay-furrow | 0.67403 | -0.37788 | -0.18281 | 0.18674 | 0.10287 |
| Clay-ridge | 0.75881 | -0.18594 | -0.02533 | -0.24177 | 0.19886 |

Table 6
Principal component scores computed for individual fields.

| Field No. | PC1 | PC2 | PC3 | PC4 | PC5 |
|---|---|---|---|---|---|
| 1 | -0.34083 | 0.83281 | -0.68419 | 0.36655 | 0.28005 |
| 2 | -0.02138 | 0.27963 | -0.3023 | 0.38353 | -0.98741 |
| 3 | 1.02136 | 2.8733 | 3.12548 | 0.4486 | -0.50195 |
| 4 | 3.01898 | -1.4103 | 0.36112 | -1.65131 | 0.78762 |
| 5 | 0.49798 | 0.9875 | -0.96651 | -1.74321 | -0.45999 |
| 6 | -0.77588 | -0.58251 | 0.84074 | 0.73235 | 0.61734 |
| 7 | -0.31447 | 0.1628 | -0.55037 | 0.23912 | 0.369 |
| 8 | -0.20558 | -0.47542 | -0.62947 | -0.00923 | 0.32541 |
| 9 | -0.45682 | -0.89806 | 0.20999 | 0.38938 | -0.15757 |
| 10 | -0.82182 | -0.54396 | 0.85226 | 0.09439 | -0.80372 |
| 11 | -1.16455 | -1.22015 | -0.01866 | 0.65643 | 0.10301 |
| 12 | -0.65288 | -0.50838 | 0.57061 | -0.6388 | -1.74125 |
| 13 | -0.55632 | 0.78692 | 0.11777 | -1.83867 | 0.60762 |
| 14 | -0.11059 | 0.55649 | -0.792 | -0.95945 | 0.3595 |
| 15 | 0.45962 | 1.38782 | -2.37177 | 0.63577 | 0.39471 |
| 16 | 0.09263 | -0.33459 | -0.33963 | -0.31231 | -1.17587 |
| 17 | -0.72722 | 0.41159 | 0.18337 | -0.10254 | -0.53223 |
| 18 | -0.3065 | 0.01967 | -0.7473 | -0.48756 | -2.09882 |
| 19 | 1.11931 | -1.60198 | 0.68637 | 0.03805 | 1.25365 |
| 20 | 0.42475 | -0.08045 | -0.09534 | 2.60825 | 0.13608 |
| 21 | 0.40773 | 1.05401 | -0.63885 | 0.67028 | 1.3599 |
| 22 | -0.81218 | 0.23166 | 0.17391 | 0.27785 | 1.94661 |
| 23 | 1.78861 | 0.75502 | -0.08323 | 1.27515 | -1.17417 |
| 24 | -1.56392 | -0.3502 | 1.098 | -1.07261 | 1.09247 |

related to available phosphorus mostly. The high loadings of Organic C-furrow and Total N-furrow silt component was considered as the available P and organic matter factor. The third component had a high correlation with pH-furrow and a moderate positive correlation with P-furrow, P-ridge and Acid –furrow. This component is the acidity and available P factor. The fourth (PC4) component showed high correlation coefficient with Total N-furrow and may be referred to as the Total N factor which also had slight correlation with Mn-ridge, Mn-furrow, Na-ridge, and acid-ridge. The fifth component was the sodium/salinity factor as only Na-furrow had high loading for this component.

Following the characterization of the derived components, component scores for each field were computed (Table 6). Using the standardized component scores as the independent variables and the grain field mean yield of each field as the dependent variable, stepwise regression analysis was carried out. Significance level for entering the model was

TABLE 7
Stepwise regression model of response variable grain 'field mean' yield.

| Variable | Partial R*2 | Model R**2 | Estimated coefficient | Prob. >F |
|---|---|---|---|---|
| Available P and Organic matter | 0.2298 | 0.2298 | 1.2268 | 0.0178 |

set at $\alpha = 0.05$. From Table 7, available P and organic matter component (PC2) explained 23% of the variability in grain yield of soybean. Other variables did not satisfy the abovementioned significance level.

The PC for each field was computed. Each of the fields was ranked based on the principal components scores. For PC1, fields number 4, 23, 19, and 3 were best. For component 2 (PC2), field number 3 was best, followed by fields 15 and 21 in that order. Considering PC3, field 3 was top again, followed by field 24. In PC 4, however, fields 20 and 21 had high ranking and at the level of PC4, fields 22, 23, 19, and 24 had high ranking in that order. However, their contributions to PC1-PC3 was low. On the whole, field No. 3 was best in the ranking followed by field No. 21.

## Discussion

Nutrients in the ridges were more correlated with the PC than those in the furrows. There was an obvious higher correlation between nutrients sampled in the ridges than those in the furrows (Table 5). Thus P, pH, OC, sand, and silt were at higher concentrations in the ridges than in the furrows. This has some implications on the soil management of the farmers. Farmers generally in this study area cultivate their land by first hoe harrowing before engaging animal traction to ridge their fields. During the land preparation period, the small amount of residual nutrients gained from the previous year in the ridges are exposed to harsh environmental conditions until the rains stabilize to ridge. It is difficult to practice a no-till or minimum tillage system in this site because of the sandy nature of the soils. Ridging preserves some level of moisture and probably minimizes nutrient loss especially N through leaching and volatilization compared to what happens to an exposed surface. Because total N had positive loading on the first component along with cation exchange capacity and clay, the first component explained that the factor determining soybean yield is based mainly on the chemico-mechanical properties of the soil. Mohanty and Filipovski (1962) had earlier reported similar findings. Even though other fields came first in the PC4 and PC5, the contribution to the determining factors was low compared with the loading in the PCs 1–3.

It was observed in this study that inoculation had little effect on the soybean parameters especially BNF and grain yield. It was then necessary to beam the searchlight on other factors. Thus, the principal component analysis of the soils revealed that soil characteristics were important when considering factors responsible for yield differences in farmers' fields. By ranking the fields based on the correlations of the soil properties with the PCs, two fields were outstanding: No. 3 and No. 21. In fact, the best farmer's field was no. 3 in all parameters measured and this result has been consistent for the past years' trials. Probably the high level of P in this particular field has been responsible for the high performance. Field 21 was next to the best field but it did not show the same potentials as the best field. Thus, this shows that P is vital in legume-cereal crop rotation and the soil P status should be above the critical level of 10–15 mg kg$^{-1}$ (Aune and Lal, 1997). The best of all the fields and its qualities could be seen in its productivity with the highest soybean grain yield, highest N derived from the atmosphere, and N balance recorded in this field. Thus for good establishment and high BNF potential, the elements in PCs 1–3 should be present at reasonable levels. The performance of soybean in the field depends to a greater extent on the availability of soil nutrients, such as N, P, and micronutrients (Sanginga *et al.*, 2001). Thus, the fact that the major plant nutrients formed the bulk of the PC1 is not a surprise but the management of these plant nutrients in the soil requires more attention to sustain soybean production.

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