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Soil Fertility Level and Cropping Practices Determining Soybean Yield in Northern East and Center of Benin

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Authors' contributions

This work was carried out in collaboration among all authors. Author FOC conducted the study under the supervision of the authors GDD and CEA. Authors AS and CEA designed the study. Author FOC wrote the protocol and the first draft of the manuscript under the supervision of author AS. Authors BO, GLA and ELA managed the literature searches. All authors collaborated to the revision and improvement of the initial draft submitted. All authors read and approved the final manuscript.

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ABSTRACT

Soybean is a food security crop in Benin due to its high nutritional value but its yield in the farmers' cropping system is very low. The present study aims to provide appropriate response to the yield variability among fields in two agro-ecological zones of Benin namely: Southern Borgou zone (AEZ 3 in the north) and cotton zone of central Benin (AEZ 5). Soil samples were collected from 0-20 cm

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depth in 120 fields (50 in the AEZ 3 and 70 in the AEZ 5). pH (water), soil organic carbon (Walkley and Black method), total nitrogen (Kjeldahl method), CEC (0.01 N ammonium acetate at pH 7 method) and available phosphorus (Bray 1) were determined in the laboratory of Soil Science Water and Environment (LSSEE) of the National Agricultural Research Institute of Benin (INRAB). Cropping system (crop rotations, soil fertility management practices) were also collected using an open ended questionnaire. Classification and regression trees (CARTs) models were used for data analyses. Soybean yield variability among the agro-ecological zones were registered and the highest yield recorded was less than 1 $t.ha^{-1}$. Considering soil characteristics, soil organic matter level was the most important variable determining yield variability. Furthermore, quantities of P applied and farmyard manure were cropping practices inducing yield variability (86.4% and 15% of the variability respectively). Our results also show that, yield differences noticed among the agro-ecological zones were induced by CEC and pH (water). The study suggested promotion of integrated soil fertility management practices to sustain soybean yield in the study area.

Keywords: Soil fertility; yield variability; farmyard manure; integrated soil fertility management; CART models.

1. INTRODUCTION

The world population is expected to increase from its current 6.7 billion to 8 billion by 2020 [1]. Greatest challenge in the 21st century is to feed the ever increasing population with the improvement and maintenance of soil health and environmental quality [2,3,4].

In Benin, most of the poor household (74%) are face food insecurity. Under this scenario, soybean crop has an important role to play as protein and oil sources for human consumption and to feed animal [5]. Due to the low protein consumption, soybean is often use against malnutrition in rural area [6]. In Benin, soybean is now a cash crop for the rural population [6]. It is the most important grain legume crop in the world [3]. Cultivation of soybean is gaining interest in Africa following high demand from the booming livestock feed industry [7]. Soybean is an economical and agronomical crop due to its high ability to assimilate atmospheric N_2 into forms that plants can use. However, symbiotic N_2 fixation in soybean has been shown to be highly sensitive to soil moisture and dry soil conditions which results in both decreased of N accumulation in the grain and soybean yield [8].

In Benin, soybean yields remain below the potential yield even when best cropping practices are used [6]. This is due to low soil fertility level and poor agronomic practices [9] and climate change. To improve crop yield, it is essential to assess the best management strategies improving crop resilience [10,11], mainly in the zones knowing high climatic risk [12]. Some researchers consider management practices to be the main cause of spatial yield variation [13]. It is commonly assumed that, yield variability is mostly caused by the existence of soil spatial heterogeneity within smallholder farmlands. However, the relative contribution of soil properties and crop management practices to yield variation depend on the spatial scale [14]. In Benin soybean yield level was found to be significantly determined by gender issues. According to [15] the men tend to be more technically efficient than women in soybean cropping systems. Moreover, some technical factors such as the use of improved varieties, use of fertilizers, plant density and fallowing in the cropping system influenced significantly soybean yield [15]. However specifics soil characteristics driving soybean yield variation have not yet been investigated.

A key question for the present study was to investigate crop management practices and soil characteristics that determine soybean yield variation among the agro-ecological zones. Such information would contribute to set improved management practices that would increase the production level. Therefore, soil and crop management variables effecting soybean yield improvement were measured. The objectives of the study were: (1) to compare the relative importance of soil properties and crop management practices in two agro-ecological zones of Benin, (2) to assess the most important variable inducing soybean yield variation among farmers' fields in the two agro-ecological zones of Benin.

2. MATERIALS AND METHODS

2.1 Study Area

The survey was carried out in two agro-ecological zones of Benin (Fig. 1): Southern

Borgou (AEZ 3) in which the investigations were made in Bembèrèkè and N'Dali municipalities and the cotton zone of the centre (in which the investigations were made in Ouessè and Glazoué municipalities) (AEZ 5).

The AEZ 3 is located between 1°10'- 3°45' E and 9°45'- 12°25' N. This zone is characterized by a unimodal rainfall distribution with an average annual rainfall less than 1000 mm and located in the Sudanese zone of Benin. The relative humidity varies from 18 to 99% while temperature fluctuates from 24 to 31°C. The Ferric and Plintic Luvisol [16] are the dominant soil types. Maize, sorghum, millet, yam, and groundnut are annual crops, cotton and soybean are the main cash crops.

The AEZ 5 is located between 1°45'- 2°24' E and 6°25'- 7°30' N. The area is under the sudano-guinean zone also call transitional zone of Benin. The annual mean temperature is between 26 and 29°C and the average annual rainfall ranges from 1000 to 1400 mm. The relative humidity varies from 69 to 97%. The Ferric and Plintic Luvisol are also the dominant soil types in the area. Black and hydromorphic soils are also found in the rivers' valleys. Maize, yam, cassava and groundnut are annual crops, cotton and soybean are also the main cash crops.

2.2 Data Collection Methods

Soybean producers sample was determined using the normal approximation of binomial variable (Dagnelie 1998):

$$N = [(U_{1-\alpha/2})^2 \times p\ (1-p)]/d^2$$

$U_{1-\alpha/2}$ = 1.96 is the normal random variable value for a probability value of α = 0.05; d is the expected error margin of any parameter to be computed from the survey, which is fixed at 5% in this study. p is the proportion of individual producing soybean. Based on the p-values from the results of the exploratory phase, a total of 300 soybean producers were surveyed, according to 170 in the AEZ 3 and 130 in the AEZ 5. In each locality, the respondents were identified using a simple random sampling technique.

The study was carried out from October to November 2017 and August to October 2018 during soybean growth period. A semi-structured questionnaire was used for data collection. Three students native from each area were recruited for the survey. Farm management information including crop rotation, intercropping, supply of farmyard manure (FYM) and type and quantity of mineral fertilizer applied and soybean yield were

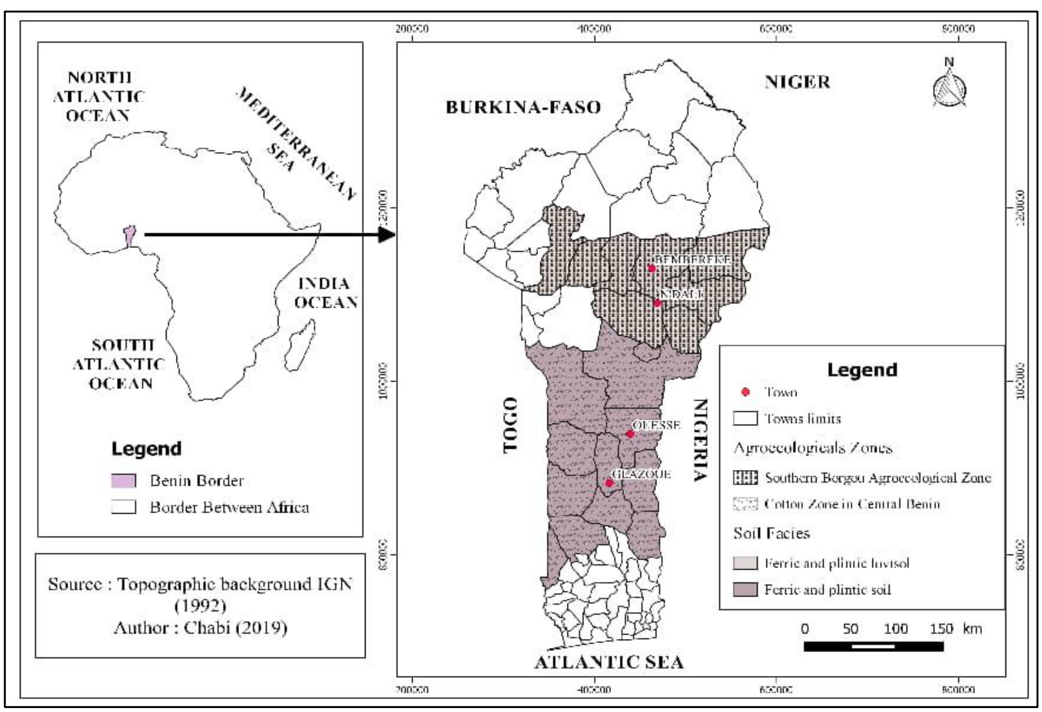

Fig. 1. Localization of the surveyed areas in the study

data collected. Quantity of N, P and K applied in each field were calculated from their respective percentages as written on the fertilizer bags. Fertilizer used in both area are NPK-SB (14-23-14-5-1) and urea (46% of N). In addition, the age and education level of the selected heads of the household were also registered. The agronomic variables used in the Classification and regression tree (CART) analysis are presented in Table 1.

2.3 Soil Sampling and Analyse Methods

Top-soil (0 - 20 cm depth) samples were collected from the selected fields. Soil properties were analyzed at the Laboratory of Soil Sciences, Water and Environment (LSSEE) of the Research Centre of Agonkanmey, National Agricultural Research Institut of Benin (INRAB). Soil pH (water) was determined using a soil-water suspension of 1:2.5 ratio. Soil organic carbon (SOC) was determined by acid digestion method (Walkley & Black, 1934). Soil total nitrogen (TN) was measured by the semi-micro Kjeldahl method. The Cation Exchange Capacity (CEC) was determined by Metson method and the available phosphorus (AP) were determined using Bray 1 method. Exchange potassium (Kexc) was determined in ammonium acetate pH 7 method and exchangeable K^+ was determined with atomic absorption spectrophotometer.

2.4 Statistical Analysis

Descriptive statistics (frequencies and means) were carried out using R 3.5.2 software. Soil characteristics and soybean yield data were subjected to one-way analysis of variance using agro-ecological zones (AEZ) as the factor. Mean differences were determined using Fisher test and regression tree analysis was used to predict or explain the response of soybean yields observed in the agro-ecological zones to soil parameters and field management practices. Classification and Regression Tree (CART) is a non-parametric statistical approach that partitions the data to find increasingly homogeneous subsets based on independent variables splitting criteria using variance minimizing algorithms. The dependent data are partitioned into a series of descending left and right child nodes derived from parent nodes [17]. Once the partitioning has ceased, the child nodes are designated as terminal nodes. Homogeneity of partitioned groups was assessed by the least squares as the loss function with a minimum proportional reduction of error (PRE) at any split of 0.05 and minimum of five objects allowed in any node.

3. RESULTS

3.1 Soil Chemical Properties and Soybean Yield

The Table 2 presents the average values of soil characteristics in the two agro-ecological zones. Soil organic carbon (SOC) content was high in the soil of the AEZ 5. The total nitrogen (TN) and SOC differ in the two AEZ. According to the pH (water) values, soils of the AEZ 5 were acid. The available phosphorus (AP) and exchangeable potassium contents were relatively similar in the two AEZ.

Table 1. Agronomic variables used in the Classification and Regression Tree (CART) analysis

Variables	Unit	Description
N	$kg.ha^{-1}$	Quantity of N applied from the fertilizer
P	$kg.ha^{-1}$	Quantity of P applied from the fertilizer
K	$kg.ha^{-1}$	Quantity of K applied from the fertilizer
Rot	None	Crop rotation in soybean cropping system
Inter	None	Intercropping with soybean or not
FYM	None	Farmyard manure supplied (0 = no manured ; 1 = manured)
Exp	Year	Experience in soybean cultivation
SA	None	Proportion of land allocated for soybean cultivation

Table 2. Soil chemical characteristics in the two AEZ

Area	Organic carbon ($g.kg^{-1}$)	Total N ($g.kg^{-1}$)	P-Bray 1 ($mg.kg^{-1}$)	Exchangeable K^+ ($cmol.kg^{-1}$)	CEC ($cmol.kg^{-1}$)	pH(water)
AEZ 3	0.68±0.06b	0.10±0.04a	10.02 ± 0.2a	0.18±0.10a	5.09±1.73b	7.08±0.67a
AEZ 5	1.27±0.25a	0.08±0.01b	11.76±0.16a	0.23±0.07a	6.55±1.24a	6.49±0.33b

Note: In a column means followed by the same alphabetic letter are not significantly different ($P > 0.05$) according the Student Newman-Keul test; AEZ 3: Southern Borgou zone; AEZ 5: Cotton zone of the centre

In the study area, soybean yield varied considerably among the fields (Fig. 2). The highest yield registered was 3.2 $t.ha^{-1}$ and the lowest 0.4 $t.ha^{-1}$. Most of the producers (60% of the respondents) had soybean yield varying between 0.4 to 0.8 $t.ha^{-1}$. Higher soybean yields were registered in the AEZ 3 compared to the AEZ 5. But this was below 1 $t.ha^{-1}$.

3.2 Soil Chemical Properties Inducing Soybean Yield Variation in the Two AEZ

Fig. 3 shows the regression tree model analysis for soybean yield as a function of soil chemical properties. It is appeared that soybean yield variation could be explained only by soil chemical properties. Based on the regression coefficients, it appeared that, high soybean yield is related to high amount of SOC and CEC. The results also showed that SOC level was the most important variable determining soybean yield variation and CEC level was the second most significantly ($P = 0.0116$) important variable. The average soybean yield in the fields with both SOC higher than 1.4 $g.kg^{-1}$ and CEC more than 5.6 $cmol.kg^{-1}$ was 1.06 $t.ha^{-1}$.

3.3 Crop Management Practices Inducing Soybean Yield Variation in the Two AEZ

The regression tree analysis carried out for soybean yields based on farmers' crop management practices (Fig. 4) shows that large part of soybean yield variation (66% for proportional reduction in error; PRE) was due to the agronomic management practices. The optimum regression tree had two splits and three terminal nodes. The first split in the three occurred at P rate of 14.65 $kg.ha^{-1}$, which suggested that the amount of P applied was the most important factor determining soybean yield. This split produced two groups of data: One was low P rate group with an average yield of 0.88 $t.ha^{-1}$ and the other was high P rate group with an average soybean yield of 1.04 $t.ha^{-1}$. This single split in the data accounted for 10% of the total variation in yield. The low P groups were further split again on the basis of FYM supply, which explained 15% of the variation. The fact that no additional splits were performed, indicated that the amount of P and FYM supplied was the main factors affecting soybean yield for these fields. Fields with low P rate and without supply of FYM had the lowest average yield.

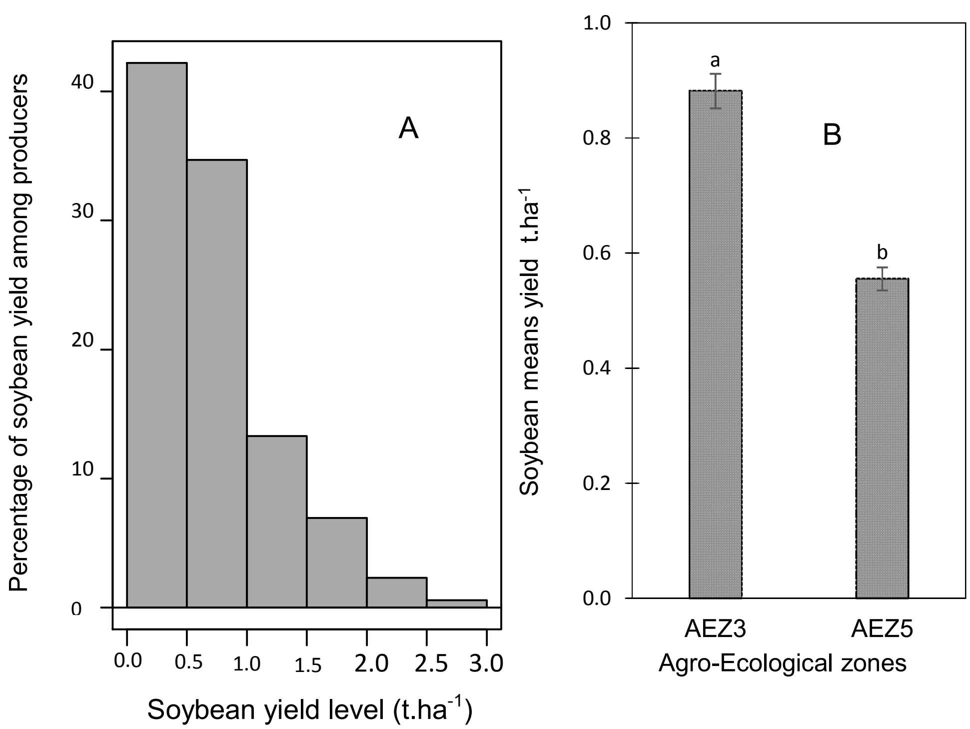

Fig. 2. Variation of the soybean yield among producers (A) and among agro-ecological zones (B)

Note: AEZ 3: Southern Borgou zone; AEZ 5: Cotton zone of the centre

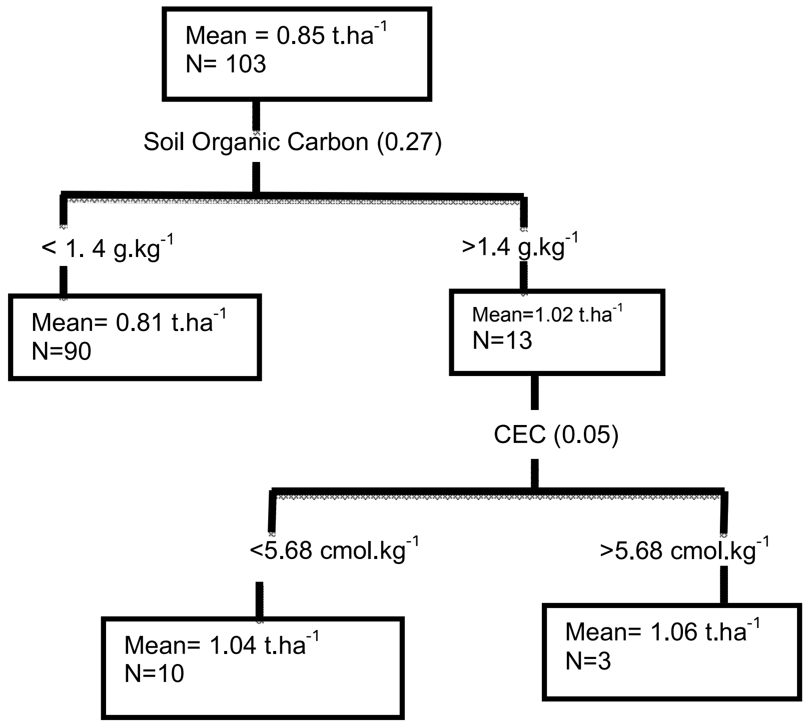

Fig. 3. Regression tree predicting soybean yields based on soil chemical parameters; each node is labeled with the average soybean yield (mean) and the number (N) of fields in that group

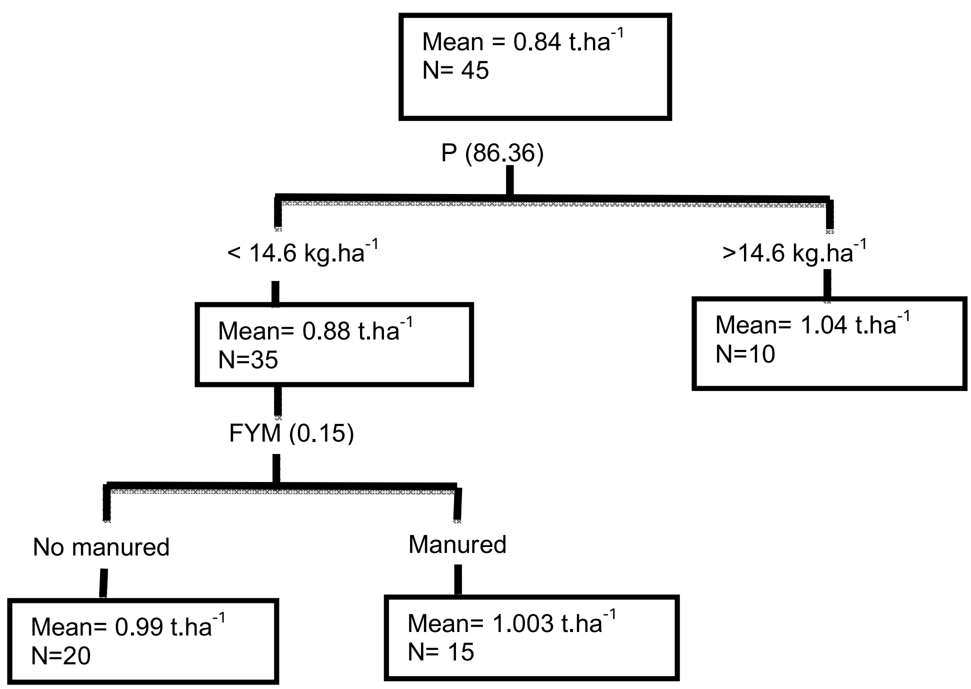

Fig. 4. Regression tree predicting soybean yields based on farmers' agronomic management practices (farm yard manure supply and quantity of P fertilizer application)

3.4 Causes of Soybean Yield Variation among the AEZ

The causes of soybean yield variation among the two AEZ were assessed based on CART analysis using the AEZ as categorical dependent variables. The yield variability among the AEZ was largely induced by variation of soil fertility level and farmers' management practices. Thus, the CEC, pH(water), quantity of P applied which explain yield variations among the two AEZ were selected as determinant factors (Fig. 5). The CEC was the primary splitting variable in the classification tree, explaining 36.7% of data variation. In most of the fields, the CEC value was less than 8.44 $cmol.kg^{-1}$ and fields with CEC value above 8.44 $cmol.kg^{-1}$ had high soybean yield. The remaining fields with CEC value under 8.44 $cmol.kg^{-1}$ were split into two groups dominated by the pH(water) value and the rate of P fertilizer applied in the field. Application of P fertilizer at a rate higher than 7.87 $kg.ha^{-1}$ in the field with pH (water) under 7.15 induced a decrease of soybean yield. This point out the important of pH in phosphorus availability in the soil to sustain leguminous crop yields.

4. DISCUSSION

Soybean grain yield remains low in the two AEZ less than 1 $t.ha^{-1}$ in most of the respondents' field. The yields are lower than that reported by several authors when soybean crop fields are well managed [18]. Our results, could be explained by the inappropriate crop management practices in both AEZ. Although most of the soils allocated for soybean cultivation in the area are degraded. Most of the farmers do not use fertilizers to improve soil fertility level and they still claim that soybean does not need fertilizers. However, several studies also show the positive effect of P fertilizer in soybean cultivation [15,18].

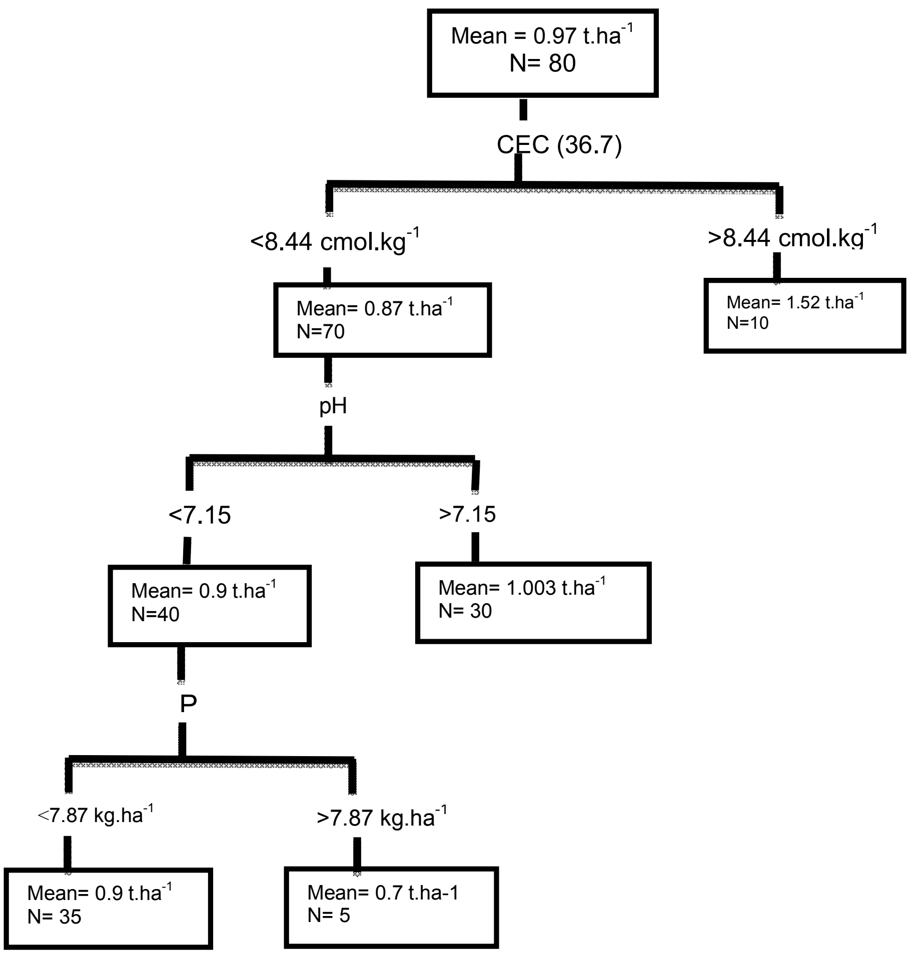

Fig. 5. Regression tree predicting soybean yield based on soil chemical characteristics and farmers' agronomic management practices

The CART models proved that SOC level was the main parameter determining soybean yield in the farmers' field. The importance of SOC level on crop yield and soil fertility was largely reported [19,20,21]. However, in the two AEZ, farmers do not apply manure in their fields especially for soybean cultivation. This could be explained by the transportation costs of the manure, availability on the manure and the use of crop residues to feed the animals. The consequence of such practice is the decrease of soil organic carbon level and in long-term induce adverse effect on soil productivity [19].

According to our finding, the most important factors affecting positively soybean yield variation were the quantity of P fertilizer applied combined with FYM. Several authors reported also the importance of P for leguminous like soybean especially for nodules formation [9,22,23]. It was shown that Ca and P were essential nutrients for root growth, nodule formation, and growth of soybean in the acid soils. Ca increased root growth, number of nodules, and growth of the soybean plant. This positive effect of Ca was increased considerably by the application of P fertilizer. Ca and P have a synergistic effect on biological nitrogen fixation (BNF) of soybean in acid soils. Ca is important for the establishment of nodules, whilst P is essential for the development and function of the formed nodules. P increase the number of nodule primordia, thus it also had an important role in the initiation of nodule formation [24]. The importance of P on leguminous BNF is well recognized [25]. In addition, soybean plants primarily dependent on N fixation require P more than N supply in order to obtain a comparable yield [9]. Moreover, several authors reported the importance of P application on the quality of soybean seed [26,27]. However, mineral fertilizer application for soybean in the area is not yet widespread. Furthermore, the type of fertilizers used are those intended for cotton crop (NPK-SB 14-23-14 5-1) which are not suitable for soybean cultivation. In addition, ours results show that the CEC and pH(water) values were also determinant to sustain soybean yield in the study area. In fact, as reported by [25,28] near neutral soil pH an increase of the total number of nodule primordia per plant and per centimeter of root length could be noticed. This could explain the relative importance of pH in soybean yield improvement registered in our study. Leaving out constraints related to soil chemical properties by using liming and adequate fertilizer doses, soybean productivity on the slight acid soil of the study area would be an issue for farmers of the study area.

5. CONCLUSION

Soybean yield is low in the two AEZ, with spatial variation among the fields. The CART analyses method used is a suitable tool predicting factors affecting yield variation. Our results showed that although variation in soil characteristics was often considered to be the major contributor to yield variation, only a small part of soybean yield variation could be explained by a change in soil chemical properties. Soybean yield variation registered was largely dependent on farmers' management practices. SOC level, dose of P fertilizer applied and pH (water) were the most important factors determining the soybean yield in the farmers' fields. This indicated that, soybean yield variation within farmers' fields can be significantly reduced by promoting best agronomic practices in the study area.

Based on these results, our study suggested to develop an appropriate nutrient management practices to sustain soybean production in the study area this could contribute in the improvement of the yield level.

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COMPETING INTERESTS

Authors have declared that no competing interests exist.

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