Using the double pot technique to detect nutrient limitations for soybean growth (*Glycine max*) in Sierra Leonean soils

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Integrated Management of Agro-systems and Landscapes

February 2014

BORDEAUX SCIENCES AGRO

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Acknowledgements

This internship was carried out within the N2Africa project as achievement of my second year in Bordeaux Sciences Agro, in pre-specialization Integrated Management of Agro-Systems and Landscapes (first year of master level). I would like to sincerely thank Greta van den Brand, from N2Africa staff project, for her considerable help through all this experience, thank you so much Greta. From N2Africa project, I also express my gratitude to Dr Linus Franke for his constructive remarks in the writing of this report. In Sierra Leone I also wish to thank the Sierra Leone Agricultural Research Institute (SLARI) members, who help me for the experiment all along my stay, to name of few Dr. Idriss Baggie for the management, and a special thank for Adonis, SLARI laboratory assistant, without whom I could not have conducted this great experiment. Finally from Bordeaux Sciences Agro thank you to Dr. Lionel Jordan-Meille for his assistance from Bordeaux.

Abstract

To detect nutrient deficiencies and the relation between pH and nutrients availability in Sierra Leonean soils for soybean (*Glycine max*) growth, a nutrient omission trial based on the double pot technique was carried out. Five different soils, known for giving low soybean yields, were tested. Each soil underwent 13 different treatments: nine nutrients treatments and four with the combination of an oyster shell treatment and four nutrient treatments. Nutrient treatments were: a control (plant only dependant on soil nutrients), a complete solution (with P, K, Ca, Mg, S and micronutrients in a nutrient solution), a complete solution with an added Nitrogen source, and treatments where P, K, Ca, Mg, S or micronutrients were individually omitted from the nutrient solution. Oyster shell treatment was used to estimate the impact on nutrient availability in the soil with a pH increase. Oyster shell powder was added into soils in combination with four nutrient treatments: control, complete solution and P or K omitted treatments.

Regular observations on soybean plant were done to detect specific symptoms. Nine days after sowing (DAS), stems height were measured every five days as a non destructive method. From 15 to 25 DAS, every five days, stem dry matter weight were taken as destructive method. Soils chemical characteristics and plants nutrient content were realised by proper laboratories. Farmer interviews were also carried out on field history management. Visual deficiencies were quotable on plant receiving K-omitted treatment, and low biomass were obtained with P and K omitted treatments for the five soils, attesting of a general deficiency for Phosphorus and Potassium in Sierra Leonean soils. The complete solution with the added Nitrogen source showed soybean plants highly more developed in comparison with the complete solution, revealing then a general soils deficiency in N too. Increase of soil pH didn’t give better biomass production; however the needed time for the oyster shell treatment before being effective can be questioned here. More specifically, Bandajuma and Kondebothiun soils with the lowest biomass production appeared as less suitable soils for soybean growth. It seemed mainly due to the poor N soil content for both of them and alsoto the very low Effective Capacity Exchange Cation for Kondebothiun. Even if Foya Jonction, Meni Curve and Gbomtrait soils appeared as more suitable for soybean growth, low pH, N and P contents were limiting plant development. Information from farmer’s interviews, as house-field distance and history of field use, also allowed to clarify the obtained results. No deficiencies were detected for calcium, magnesium, sulphur and micronutrients (Zn, Cu, Fe, B, Mo).

Keywords: nutrient omission trials, oyster shell treatment, double-pot technique, *Glycine max*, Sierra Leonean soils.

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Introduction

Soil fertility is decreasing in many parts of Africa and is today, one of the major challenges the continent has to face. Population growth is leading to the intensification of agriculture with increased cultivated areas and decreased fallow times (Sanginga, 2003). According to Hougnandan et al. (2000) in Benin, maize yields decreased from 3t/ha to 0.7t/ha when the fallow period changed from 6 to 2 years. Such intensification is not sustainable if it does not coincide with improved farming techniques.

The N2Africa project works in 11 African countries with smallholder farmers growing legume crops for biological nitrogen fixation. Legumes have the ability to fix nitrogen (N_2) from the atmosphere via bacteria, rhizobia, which live in symbioses with legumes.When the right rhizobia encounter the legume root, they infect the root and a nodule forms. In the nodule, the rhizobia fix atmospheric nitrogen into a form that the plant can use. After crop harvest, when legume residues are left in the field, part of the fixed nitrogen can become available for the following crop. Biologically fixing nitrogen through legumes is also very cheap compared to buying mineral nitrogen fertilizer, especially in Africa where fertilizer prices are among the highest of the world (Batino et al. 2006).Even though green manures such as herbaceous and woody legumes can commonly contribute from 40 to 70 kg Nha^{-1}per season according to Sanginga (2003), many farmers do not like this practice. It implies indeed more working time and labour without getting any edible or marketable yield. Although grain legumes usually fix less nitrogen than other legumes types such as green manure, N2Africa prefers working with grain legumes that provide a more direct return to investments.

Sierra Leonean soils are mainly ferrasols. They are characterized as highly weathered (Deckers 1993) and with low capacity for supplying nutrients to plant and retaining them (Bationo et al. 2006). The high rainfall in the region leads to a high nutrient leaching unfavorable for plant growth, as well as soil acidity and aluminum toxicity. Thus even though legumes such as soybean can improve soil properties, research must be done to adapt these crops to such difficult conditions. Sanginga(2003) also mentions that when a soil is deficient in nutrients such as phosphorus, nitrogen fixation is reduced. Thus the possible nitrogen contribution provided by legumes can then be limited (Baggie et al. 2012).Moreover nutrients other than N, P and K could slow down plant production(Nziguheba et al. 2008).

In this study,the aim was to detect nutrient deficiencies in a variety of Sierra Leonean soils that constrain soybean growth. To assess this, a nutrient omission trial has been conducted using the double pot technique, developed by Janssen in 1974. Five different soils have been selected in 3 districts of Sierra Leone, where soybean (*Glycine max*) has been cultivated and were yields were low. For a better understanding of farm and field managements, interviews have been carried out from where soils have been taken from. This study contributes to refining fertilizer recommendations in soybean on Sierra Leonean soils.The experiment took place within the Sierra Leone Agricultural Research Institute (SLARI), in Rokupr station.

Materials and Methods

Experimental Design: the double pot technique

For rapid identification of the nutrients that are in short supply in the soil, the double-pot technique has been developed by Janssen in 1974 (Janssen, 1990). This technique consists of 2 separated pots (Figure 1), from which the plant takes up its nutrients:

-An upper pot is filled with soil. The seed is sown in this one.

-Below this pot a second one is set up, containing a nutrient solution.

The plant can use nutrients from both pots for its growth and development. When a specific nutrient is omitted in the nutrient solution, the plant can take it up from the soil only. If the soil cannot provide the omitted nutrient in sufficient quantity, deficiency symptoms are observed on the plant, such as limited growth, leaf chlorosis, etc. The deficiency symptoms in combination with knowledge on which nutrient is omitted from the solution allows determination of growth-limiting nutrients.

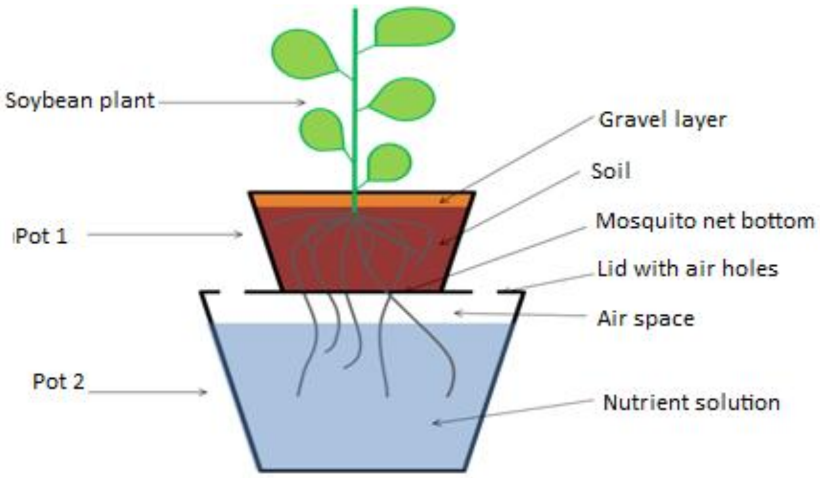

Figure 1: Illustration of the double pot experiment

In the upper pot (Pot 1), the soil was covered by a layer of gravel to avoid water loss. A mosquito net with 2mm holes was used as interface between Pot 1 and 2. In order to support the weight of Pot 1 a perforated lid was placed on the Pot 2. The lid had an opening allowing root development. An air space of 1 cm was left between the nutrient solution and the lid of Pot 2. The upper pot had a volume of 1l and was filled with 250g of soil. The bottom one has a volume of 1.8l.Pictures of the experimental model are available in Appendix I.

Experimental Factors and Design

Three experimental factors were tested:

- ✓ The first factor was the soil. Soils from five different sites were tested. Sites were chosen based on bad performance of soybean in the past.
- ✓ The second factor was the nutrient solution. The nutrient solution varied in nutrient composition. In total there were 8 different nutrient solutions.
- ✓ The third factor was the oyster shell treatment. Oyster shell was used to reduce soil acidity in the four main treatments, i.e. the control, complete, -P and -K solutions.

Soil preparation and oyster shell treatments is described in the next section: Site Selection and Soil Sampling.

For the nutrient solutions, the following macronutrients were used: Phosphorus (P) 0.5mmol/l, Potassium (K) 3.0mmol/l, Calcium (Ca) 2.5mmol/l, Magnesium (Mg) 1.0mmol/l, Sulphate (S) 1.0mmol/l, and Nitrogen (N) 7.5mmol/l. The micronutrients used were Manganese (Mn) 7.4 µmol/l, Zinc (Zn) 0.96 µmol/l, Copper (Cu) 1.04 µmol/l, Boron (B) 7.13 µmol/l, Molybdenum (Mo)0.01 µmol/l and Iron (Fe) 35mg/l. The description of the nutrient supply is available in Appendix II. The calculations for the nutrient solution calculations are available in Appendix III.

The 13 following different treatments were integrated:

- ✓ 1 control

Treatment code	Nutrient treatment	Nutrients composition in Pot 2
1	Control	only rainwater

- ✓ 8 nutrient treatments

Treatment code	Nutrient treatment	Nutrients composition in Pot 2
2	Complete solution	P,K, Mg, Ca, S, micronutrients
3	Complete solution + N	P,K, Mg, Ca, S, micronutrients + N
4	P omitted	K, Mg, Ca, S, micronutrients
5	K omitted	P, Mg, Ca, S, micronutrients
6	Mg omitted	P,K, Ca, S, micronutrients
7	S omitted	P,K, Mg, Ca,micronutrients
8	Ca omitted	P, K, Mg, S, micronutrients
9	Micronutrients omitted	P,K, Mg, Ca, S,

- ✓ 4 oyster shell and nutrient treatments

Treatment code	Nutrient treatment	Oyster shell treatment in Pot 1	Nutrients composition in Pot 2
10	Control	Yes	distilled water
11	Complete solution	Yes	P,K, Mg, Ca, S, micronutrients
12	P omitted	Yes	K, Mg, Ca, S, micronutrients
13	K omitted	Yes	P, Mg, Ca, S, micronutrients

Treatment number 3 had an additional nitrogen source, whereas all other treatments had a nitrogen free solution. Although soybean has the ability to fix nitrogen, it was decided to have one treatment including nitrogen, due to indications of nitrogen deficiencies in preliminary double-pot experiments. The TGx 1951-4F soybean variety was used and legumfix for seeds inoculation.

Oyster shell treatment was applied in soil of the control, the complete solution, K omitted and P omitted solutions, since the availability of P is notably restricted by a low pH and may be a reason for low yields. The objective was to investigate the additional effects of increasing the pH. Usually lime is applied into the soil to increase the pH. In Sierra Leone lime is not available, but ground oyster shell is used. Such a practice is only used at experimental level, because of the long process that grinding oyster shell implies. Oyster shells have been ground manually in a wooden mortar and sieved though 2 mm to only obtain fine particles, which were added to the soil. To determine the right amount of oyster shell powder to add into the soil, different pH analyses have been done. The analyses showed that 0.5g of oyster shell for 10g of soil was sufficient to change the soil pH from 5.0 to 6.8. Thus a proportion of 1/20 has been used in pots undergoing the oyster shell treatment. For a pot filled by 250g of soil, 12.5g of oyster shell powder was added. Seeds were added directly after the filling of the pot. See Appendix IV, for the description of the preparation process of the oyster shell treatment.

For each treatment, 1 stock solution, 250 times more concentrated was prepared. The prepared volume for each stock solution was 2.5l. The volume of the bottom pot (pot 2) was 1.8l.7.8ml of the respective stock solution were added in the bottom pot. Appendix V shows the total amount of nutrients used for the experiment.

Because distilled water was not available in Sierra Leone in large enough quantities, rain water was used for watering and for the nutrient solutions. Rain water was collected in big containers placed in the screen house below holes in the plastic sheet in order to avoid all contaminations of metallic roofs. Samples of used rain water were analysed by LCA laboratory in Bordeaux.

Site Selection and Soil Sampling

The site selection has been done in collaboration with SLARI. The aim was to select soil from sites where it is suspected that nutrient deficiencies are limiting soybean growth, rather than e.g. management factors. Five different soil types were used in the experiment. Two sites in Moyamba district: Foya Junction and Kodenbothiun, two sites in Kambia district: Meri Curve and Gbomtrait and one site in Bo district: Bandajuma (Figure 2).

Figure 2: Map of Sierra Leone with site location

Soil samples were taken from the field in 4 to 5 randomly selected points, from a depth of 0-20cm. The subsamples were then mixed together to obtain a representative part of soil. A W-pattern was not used to take the soil samples due to the dense vegetation in the field. In four sites, soil collection took place during the fallow period and a canopy of one year old vegetation was on the field. Consequently soil access was quite limited, because most of the time vegetation had to be removed before collecting the soil. Soil was air dried and manually sieved though 2 mm for removing larger particles. See pictures on Appendix VI for an overview of soil sampling.

For each soil, analyses were done to determine important soil properties as soil texture, pH and Contents of Organic Carbon, N, P, cations as well as micronutrients. Analyses were done in the IITA laboratory in Ibadan, Nigeria. Particle sizes were obtained using the hydrometer method. For determining pH a 1/2 soil water volume ratio was used, organic carbon and total N were analysed using dry combustion method, and available P through Olsen method. Exchangeable cations (K, Mg, Na, and Ca) were determined using ammonium acetate extraction.

To determine the nutrient uptake of the plants, a dried sample of the plant was sent to the laboratory LCA in Bordeaux to estimate it. ICP method (Inductively Coupled Plasma), a laboratory intern spectrometric method, was used for the estimation. Only K, P, Ca and Mg were analysed because of the small amount of plant material sent to the laboratory.

Setup and Experimental Management

The experiment was conducted in the green house of SLARI in Rokupr Station.

Figure 3: Experimental set up in SLARI station, Rokupr

The following table is mainly based on the procedure of the double pot technique implemented by B.H. Jassen in 1974. It describes the step used to implement the experiment.

Table 1: Procedure of the double pot technique

1/ Pre-treatment of the soil	The soil was air-dried and sieved through a 2mm sieve. Stones, twigs, etc. has been removed.
2/ Filling of the pots	The volume of the upper pot, pot 1, was 1.5l, containing250g of soil. The volume of the bottom pot, pot 2, was 1.8L, filled by the nutrient solution. *The following steps have been done:* -Mix 250g of the air dried and sieved soil with a quantity of water that corresponds with about ¾ of the water needed for the field capacity, in the pot 1. -Mix Inoculum with honey to really ensure adherence to seeds and inoculate them. -Sow 4 seeds at 1.5cm depth. -Put the remainder of the water till field capacity of the soil. -Place the pot on the lid of the bottom pot, pot 2. The lid should be previously put on the pot 2. -An air layer of 1-1.5cm thick between pot 1 and 2 should be left.
3/ Treatment during growth	The experiment lasted until 25 days after sowing. As soon as the sprouts appeared above the soil the paper was removed. When the plants were large enough, they were thinned to one and a gravel layer of 0.5-1cm has been added to avoid evaporation. Watering has been done once a day with rain water, with the same amount each time. Concerning the nutrient solutions, rain water has been regularly added and the pH of the solution was kept at 6-7 using NaOH or HCl. It has been also renewed two weeks after emergence and then once a week, i.e. 2 times for this experiment. Every 5 days an examination describing the general aspect of the plant as possible symptoms has been done. Photos have been also taken to help recognizing and storing symptoms of deficiency or disease

Harvest, Measurements and Calculations

The plants were harvested at 15, 20 or 25day after sowing (DAS). However, if a plant really suffered from deficiencies or disease it was decided to not let it grow until the harvest date. Plants which died before the harvest dates were not included in the results, because plant death didn't appear as a symptom due to the received treatment, indeed on the 13 treatments, nine of them had at least a dead plant. Soils equally didn't appear as related to plant death. Every five days during the plants observations, measures of stem height were done in order to calculate a cumulative growth rate (see next section Mathematical and Statistical Analyses). When a plant was harvested the height of the stem and the weight of above ground part of the plant were measured. The dry weight was determined after oven drying at 70°C for 72 hours. Oven space and capacity was limited and biomass from three replicates was oven dried together. As a result, the biomass dry weights were available only as averages of the three replicates.

Mathematical and Statistical Analyses

From the stem height and shoot dry weight measures, a relative growth rate (RGR) was calculated with the following formula:$\frac{\boldsymbol{ln}(\boldsymbol{S2})-\mathbf{ln}(\boldsymbol{S1})}{\boldsymbol{t2}-\boldsymbol{t1}}$, with ***S*** as plant's height or weight and ***t*** as day of sowing.

When average heights or weights were calculated, also standard errors of the mean (also called the standard deviation of the mean) were calculated It is calculated with this formula: **SEM =** $\frac{\boldsymbol{\sigma}}{\sqrt{(\boldsymbol{n})}}$ **,** with $\sigma$the population standard deviation and n is the sample size. Nevertheless the accuracy of the formula was reduced because directly expressed from averages of the three replicates.

Interviews

Interviews of farmers on the management history of the field, where soil samples came from, and general question about the farm were conducted. Interviews allowed to have a better overview and understanding of soil management and the possible way to improve it. The questionnaire is available in Appendix VII and results in Appendix VIII.

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Results

Plant observations

Plant observation was daily done during the growing period. Three to five days after sowing all plants had emerged. Generally root system were visible one day earlier, all plants had then access to the nutrient solution maximum 5 days after sowing. Figure 4 shows development from 15 to 25 days after sowing, with plants receiving control or complete + N treatments where development differences were important all over the experiment.

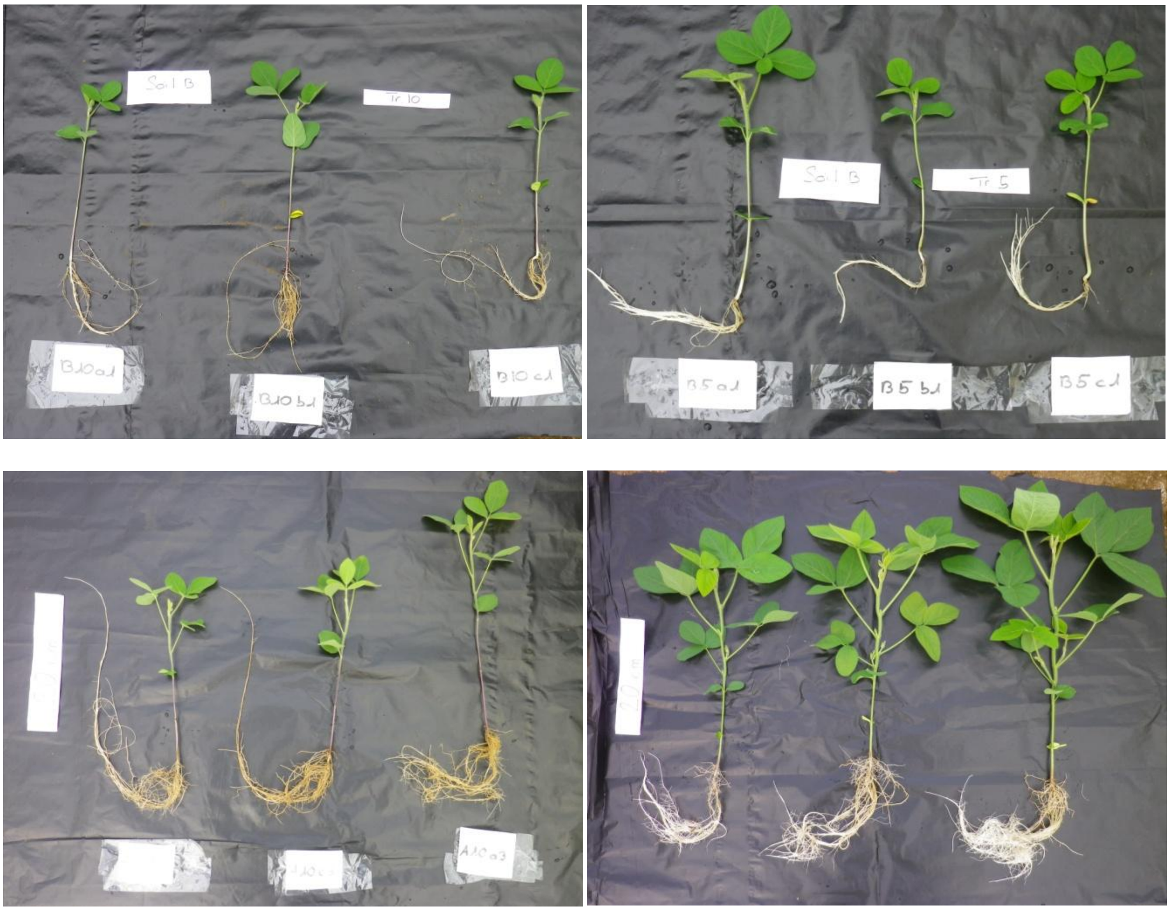

Figure 4: Plant development 15 to 25 days after sowing

From left to right: above pictures represent the 3 replicates of the control and complete + N treatments, 15 days after sowing from Bandajuma soil, below pictures the 3 replicates of the control and complete + N treatments, 25 days after sowing from Gbomtrait soil.

Nodules were visible from the first harvest. It was not the case for all the plants. The more plants were developed, i.e. the ones receiving the most complete nutrient solutions (complete or omitted micronutrient treatments), the higher the likelihood the presence of nodules was. On plants receiving the complete treatment + N no nodules at all were observed from the first harvest to the final one (Figure 5).

Figure 5: Presence or not of nodules on root system from 15 to 25 days after sowing

From left to right: above pictures represent soybean root 15 days after sowing with nodules and without when receiving, respectively, the complete treatment and the complete + N treatment, as for the bottom ones, 25 days after sowing from Bandajuma soil.

The presence of grey or brown spots on leaves typically occurred on soybean receiving the K omitted nutrient solution even when oyster shell was added to the soil (Figure 6). It highlighted potassium deficiencies in soils of all sites. It was the only specific symptom due to a specific treatment, for other treatments only plant development (height and weight) has allowed to really make distinctions among plants.

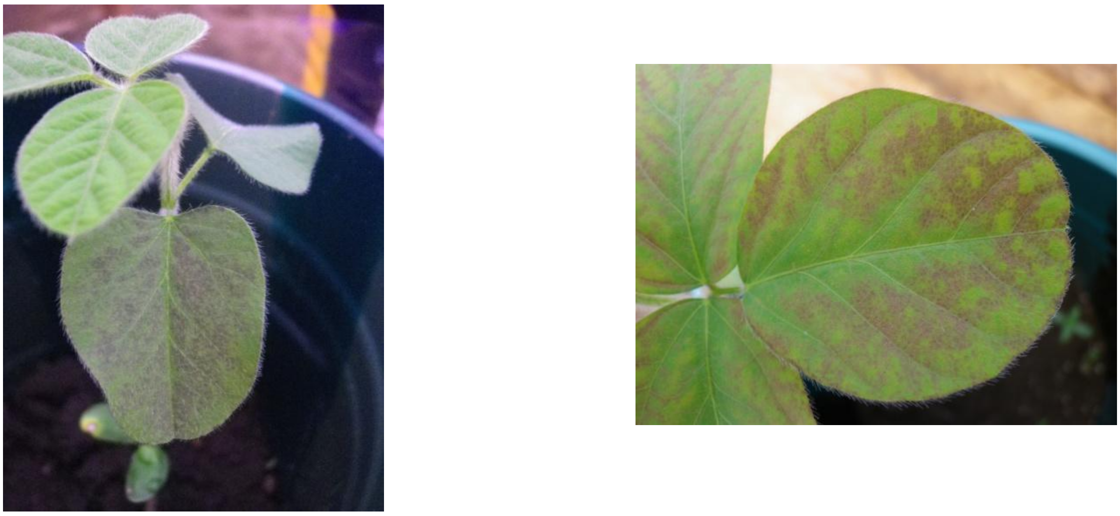

Figure 6: Grey and brown spots on soybean leaves receiving K omitted treatment

On the left to right: plant 12 days after sowing from Bandajuma soil with K omitted treatment, and plant 21 days after sowing from Foya Junction soil with K omitted and oyster shell treatment.

When spots were present, leaves progressively became yellow to rust colour from the older leaves to the younger (Figure 7).

Figure 7: Evolution of K deficiencies leave symptoms from 21 to 25 days after sowing

Figure 8 shows the differences between plants receiving the K omitted treatment (picture on the left) and those receiving the P omitted treatment (without any visual symptoms, picture on the right). It should be noticed that the yellowing of leaves, due to K deficiencies, seemed to be earlier for soybean with oyster shell treatment than without, as if higher pH increases symptom spreading.

Figure 8: from left to right soybean receiving K omitted treatment and Soybean receiving P omitted treatment (without any visual symptoms)

Figure 9 shows all the soybean plants from Meni Curve soil 25 days after sowing. High level of development can be observed for soybean receiving complete + N treatment (D). It also did not show differences between plant receiving an oyster shell treatment (B, E, H, J) than the ones without (A, D, G, I). Controls and soybeans with a P omitted treatment (A, B, and G, H) had the lowest development. Plants with K omitted treatment (I and J) were quite frail with a lot of yellow leaves as described above. Plants receiving Ca, Mg, S or micronutrients omitted treatment (respectively K, L, M) did not show signs of deficiencies being as good as the complete treatment (D and E).

Figure 9: Differences in height and weight of soybean plants 25 day after sowing due to different nutrient treatments

A: Control

B: Control + OS

C: Complete treatment + N

D: Complete treatment

E: Complete treatment + OS

F: micronutrients omitted treatment

G: P omitted treatment

H: P omitted treatment + OS

I: K omitted treatment

J: K omitted treatment + OS

K: Ca omitted treatment

L: Mg omitted treatment

M: S omitted treatment

Relative Growth Rate of the Stem

Figure 10 shows the average RGRs, averaged over the different nutrient treatments of the soybean plants for the different soils. Soils from Bandajuma and Kondebotihnn had the lowest RGR, and soil from Foya Junction the highest. Soils from Gbomtrait and Meni Curve have an intermediate RGR2 but almost reach, at the end, the same RGR as Foya Junction soil. The general trend is similar for all soils. RGRs are relatively high in all soils between days 9 and 14 days after sowing, but decrease between days 14 and 19. Between days 19 and 25 the RGRs increase again a little bit.

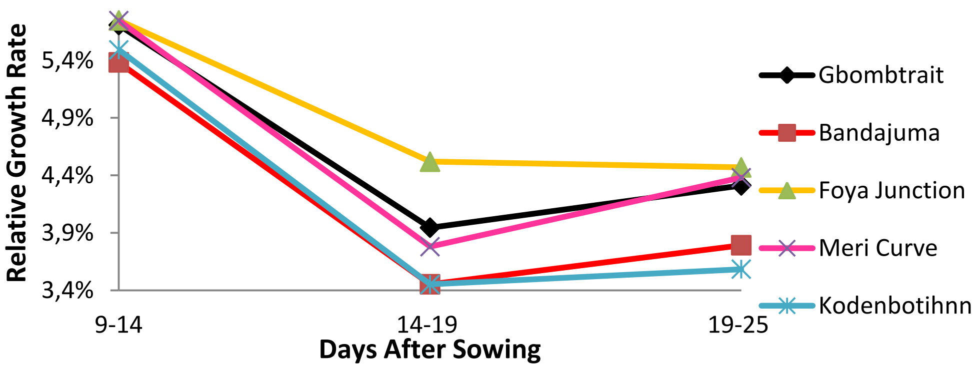

Figure 10: RGR of soybean main stem for different type of soils between 9 and 25 days after sowing

Figure11 shows the plant's RGR under different nutrient treatments, averaged for all sites. Three main trends can be highlighted. Omitting P from the nutrient solutions gave lowest RGRs, comparable to the control without any nutrients. Omitting other nutrients did not have large effects on the RGRs compared to the complete solutions. Surprisingly, adding N to the nutrient solutions highly increased the RGR compared to the complete solution.

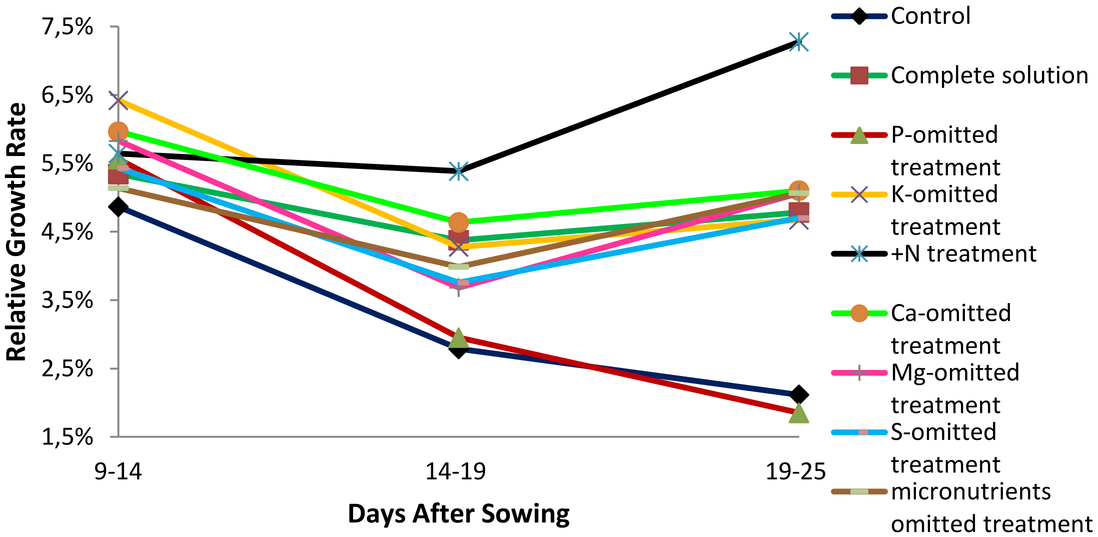

Figure11: RGR of soybean main stem for different nutrient treatments between 9 and 25 days after sowing

Figure 12 shows soybean main stem RGRs for main nutrient treatments with and without Oyster Shell treatments. For K-omitted and complete treatments, the addition of OS to increase soil's pH did not improve the development of the stem in terms of height. In the K-treatment, RGR between 19-25 days after sowing even decreased with 1.1% when OS was added. Also in the P-omitted treatments, RGR with OS were smaller than without OS. In the control treatment, however, RGR was higher with OS than without (RGR3=2.1%without OS, and RGR3=2.8% with).

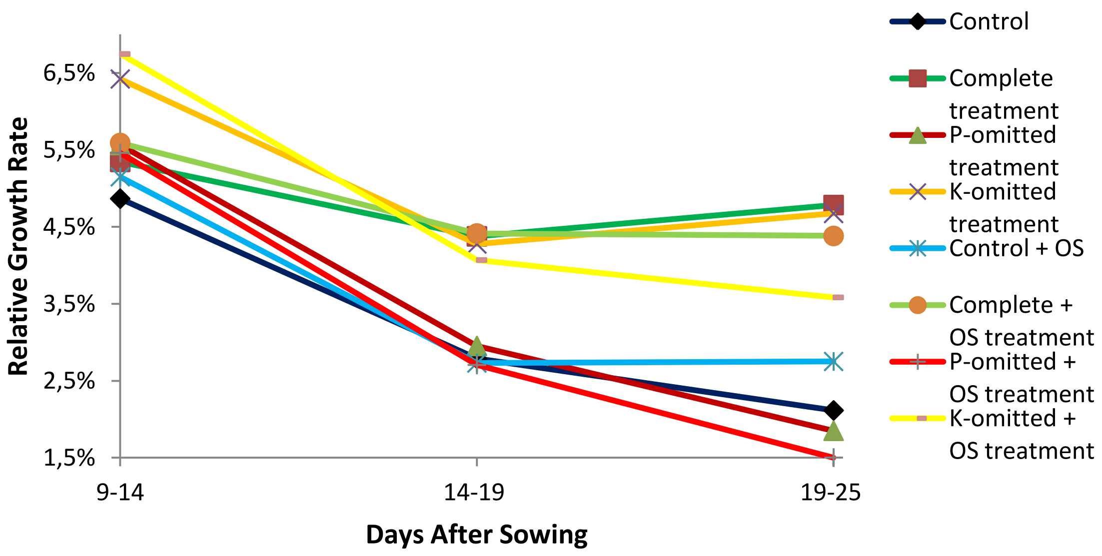

Figure 12: RGR of soybean main stem for main nutrient treatments with and without Oyster Shell treatments between 9 and 25 days after sowing

Biomass

Figure 13 shows the average biomass production in different types of soils. On average, the highest biomass developed in Foya Junction soil and the lowest biomass developed in Bandajuma and Kondebotihun soils. The average biomass development in the soils from Gbombtrait and Meni Curve were around the average for all soils, which is 0.94 g.

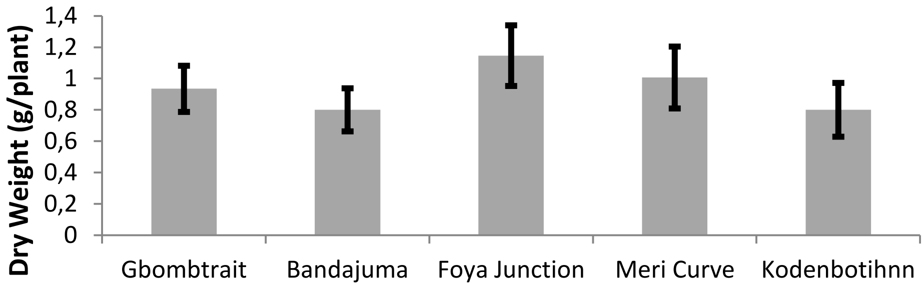

Figure 13: Dry weights of soybean shoot in g per plant 25 days after sowing.

Error bars represent the standard error of means calculated from averages of treatments.

Figure 14 shows the dry weight of the plants according to the different nutrient treatments. 4 main domains with 4 distinct standard errors of means can be observed. One with the smallest dry weigh (0.43g) represented by the control and the P-omitted treatment. One with K-omitted treatment alone, which get a better dry weigh than the control (0.65g). Another one with the complete, Ca-omitted, Mg-omitted, S-omitted and micronutrients omitted treatments which have a quite similar dry weight (≈1.16g). And then the last domain for the compete treatment with an added nitrogen source (2.52g).

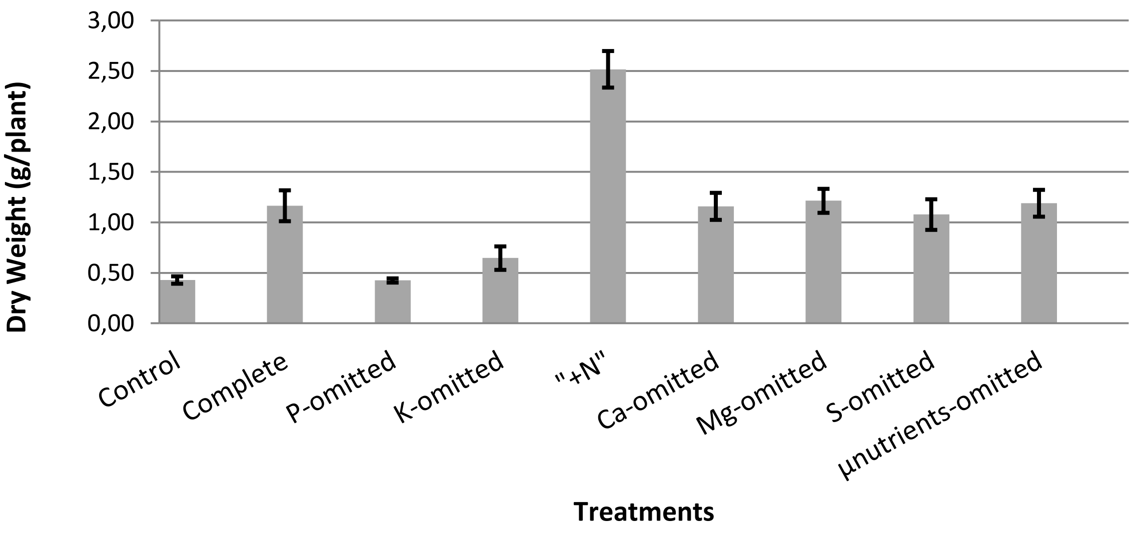

Figure 14: Dry weights of soybean shoot in g per plant 25 days after sowing under different nutrient treatments

Dry weight for the complete treatment + Nitrogen is twice as high as that of the complete one. For other treatments with one element missing, all the dry weights are equal or above the dry weight of the control. Nevertheless treatments without P and K have a relatively low dry weight in comparison with other treatments (Ca-, Mg-, S-, micronutrients-omitted) which have a quite similar dry weight with the complete treatment. Hence it highlights the importance of P and K nutrients, after N, for plant growth.

In addition to having the highest biomass after25days in the +N nutrient treatment, the development of the biomass was also faster in this treatment than in the other treatments, with higher RGRs calculated from the dry weight measures(Figure 15). Biomass RGRs were very low in the control and P-omitted treatments. Plants receiving the K-omitted treatment showed the same development as plants which received the Ca-, Mg-, S-, micronutrients-omitted treatments. However, the relative growth rate of plants receiving K-omitted treatment was about from 2 to 4% lower than under those other treatments.

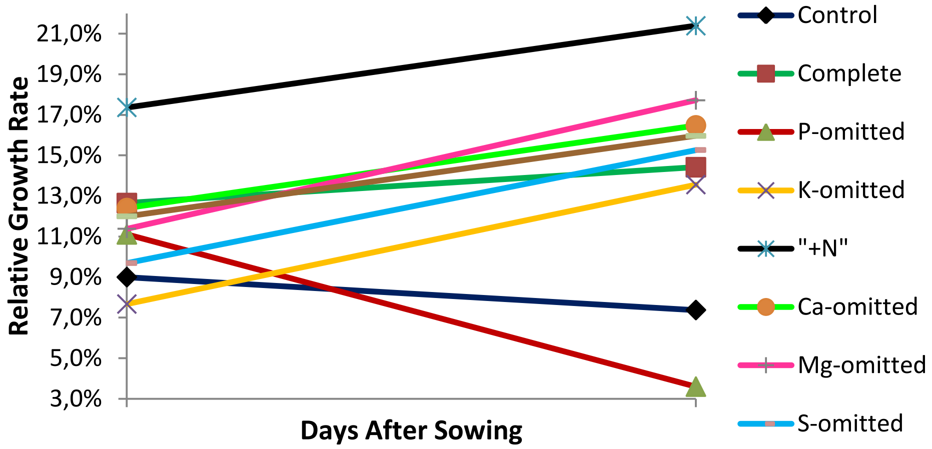

Figure 15: Relative growth rate of soybean biomass production for different nutrient treatments between 15 and 25 days after sowing

Figure 16 shows the dry weight of the soybean biomass including the influence of Oyster Shell (OS). The influence of OS on biomass was small, with somewhat lower weights for the complete and K-omitted treatments with OS than in the complete and K-omitted solutions without OS. For control and P-omitted treatments there is no difference at all.

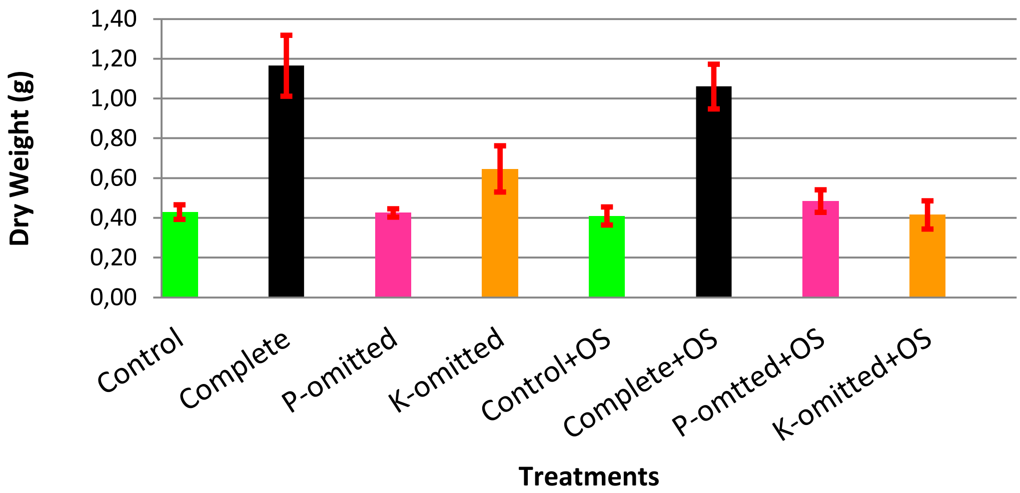

Figure 16: Dry weight, in g per plant, with and without Oyster Shell (OS) treatments

Soil characteristics

Table 2 shows the results of the chemical analysis of the different soils. Soils from Gbomtrait, Bandajuma, Foya Junction and Meni Curve approximately have the same texture with 60-68% sand, while Kondebotihun has a lower amount of sand and a higher clay quantity. All these soils can be classified as sandy-clay loams.

Meni Curve soil has the lowest pH (4.2) and Bandajuma soil the highest (5.2). All soils can be then classified as acidic. The Organic Content (OC) of Gbombtrait, Foya Junction and Meni Curve soil are around 2.9, which is almost the typical value of Oxisol (OC=3%, from Brady, 1990), which are the dominant soils of Sierra Leone (Deckers, 1993). Percentage of Nitrogen is above 0.3 for Gbomtrait, Foya Junction and Meni Curve. Bandajuma and Kondebotihun soils have a nitrogen percentage around 0.18 and 0.19. Phosphorous availability ranges from 3.2 ppm to 4.0 ppm, and can be classified as very low (<12.0) for all soils. The relative proportion of all the cations has been calculated (but not included in the present report) and do not indicate any problems. Only Kondebotihun soil has a potassium value under 0.2 which is often seen as the critical value for maize. All the CECs are under 6, it means that all those soils have a poor capacity to retain and store cations. Kondebothiun soil has the lowest CEC (2.48) and Foya Junction the highest (5.18).

Table 2: Soil chemical characteristics of the soils assessed in the nutrient omission trial

					Exchangable cations (cmol+/kg)						Micronutrients (ppm)			
Site	pH	OC	N	Olsen P	Ca	Mg	K	Na	Exch. Acidity	ECEC	Zn	Cu	Mn	Fe
Gbombtrait	4.9	3.0	0.31	3.4	3.3	0.71	0.31	0.11	0.17	4.6	5.0	2.6	7.0	86.7
Bandajuma	5.2	2.6	0.19	3.6	3.9	0.58	0.30	0.08	0.17	5.0	7.0	1.7	7.8	130.7
Kondebotihun	4.5	2.4	0.18	3.3	1.6	0.38	0.17	0.11	0.25	2.5	6.0	2.6	1.8	128.4
Foya Junction	4.5	2.8	0.37	4.0	3.7	0.72	0.43	0.11	0.25	5.2	6.5	2.6	10.7	118.3
MeniCurve	4.2	2.8	0.30	3.2	2.5	0.53	0.33	0.13	0.42	3.9	5.0	1.7	4.2	109.3

Table 3 shows the soybean dry weight in grams segregated by the different soils and the different nutrient treatments. Control treatments show that without any nutrient treatments, Gbomtrait soil seems to be more suitable for soybean growth, followed by Foya Junction and Meni Curve soils in terms of biomass. In the control treatments, lowest biomass was observed in soils from Bandajuma and Kondebothiun. These results seem to be due to the soils' Nitrogen and OC percentage. Indeed the first three ones have a percentage above 0.3% whereas Bandajuma and Kondebothiun have one around 0.18% for N and respectively an OC around 2.9 and 2.5. With higher N and OC soils content better were the plant biomass.

When plants receive all the nutrients, Foya Junction soil allows to get a better dry weight (1.7g), and seems consequently more suitable for soybean growth in comparison with the other soils, which get approximately the same dry weight (≈1g). Results are similar for complete treatment where micronutrients are omitted. Same conclusions can be done when nitrogen is added to the complete treatment. Good suitability of Foya Junction seems then due to other properties than just nutrients. It should be noticed that Meni Curve soil has a dry weight as important as Foya Junction when nitrogen is added.

Results for K-omitted treatments are in accordance with chemical analyses, that is to say, a better dry weight for Foya Junction and Meni Curve soils (0.43 cmol/kg of K for Foya Junction), then come Gbontrait soil and finally Bandajuma and Kondebotihun soils (0.17 cmol/kg of K for Kondebotihun). It is also the case for Mg-omitted treatment which is in accordance with chemical analyses. Gbomtrait and Foya Junction soils have a higher magnesium content (0.71 cmol/kg) than Bandajuma, Meni Curve and Kondebotihun soils (0.38-0.58 cmol/kg), and consequently seems to suffer less from magnesium omission.

For Ca-omitted treatment Foya Junction soil still have the highest dry weight, followed by Meni Curve and then Gbomtrait, Bandajuma and Kondebotihun soils. This is expected for Kondebotihun which has a small soil amount of calcium (1.56 cmol/kg), but not for Gbomtrait and Bandajuma which have approximately the same amount of calcium as the two other soils.

For the P-omitted treatment, Kondebotihun soil seems to suffer more when phosphorus is missing in comparison with the other soils which have quite similar dry weight. Chemical analyses, for all soils showed nevertheless a very low P content ranging from 3.2 to 4.0, and do not allow to make here distinctions among the 5 soils.

For Oyster Shell treatments according to the nutrients omitted and the type of soil, results are highly variable and no conclusions can be made.

Table 3: Plant dry weight in grams according to the 5 different soils and the different treatments

Soil	Gbombtrait	Bandajuma	Foya Junction	MeniCurve	Kondebotihun
Treatment	Biomass (g/plant)	Biomass (g/plant)	Biomass (g/plant)	Biomass (g/plant)	Biomass (g/plant)
Control	0.55	0.38	0.44	0.45	0.33
Total	0.95	0.93	1.75	1.19	1.02
"-micronutrients"	1.18	0.97	1.68	1.17	0.94
"+N"	2.17	2.10	2.82	3.03	2.46
"-K"	0.62	0.44	0.97	0.85	0.36
"-Mg"	1.55	1.02	1.44	0.96	1.10
"-Ca"	0.95	1.04	1.60	1.33	0.88
"-P"	0.45	0.46	0.44	0.44	0.34
"-S"	1.15	1.14	1.14	1.44	0.52
Control + OS	0.35	0.30	0.48	0.55	0.38
Total + OS	1.27	0.83	0.91	0.90	1.39
"-P" + OS	0.38	0.46	0.69	0.39	0.50
"-K" + OS	0.60	0.35	0.54	0.39	0.20

Plant nutrient concentration

Table 4 and Table 5 show the plant nutrient concentration according to the nutrient treatment. Important concentrations in Calcium and Magnesium in control samples can be observed (15.0 mg/g DM and 4.7 mg/g respectively), in comparison with samples receiving the complete treatment (11.7mg/g DM and 4.5mg/g DM respectively). Nevertheless when results are expressed in g by plant these concentrations become lower. When Ca was omitted in the nutrient solution, calcium shoot concentration was lower (9.2 mg/g DM), as well when sulphate was omitted (8.8 mg/g DM).When Mg was omitted from the nutrient solution Mg concentration in shoot tissue was not specifically affected. Magnesium seems then not be missing from Sierra Leonean soils. When OS was added to the soil, the calcium concentration was consequently higher in the shoot. On the contrary with oyster shell treatment the magnesium concentration was always lower for all samples.

Phosphate and Potassium concentration were highly affected when those nutrients were omitted in their respective nutrient treatment (for P: 1.6 mg/g DM for the control instead of 7.0 mg/g DM for complete solution, and for K: 14.6 mg/g DM for the control instead of 29.6 mg/g for the complete solution). The omission of calcium, magnesium, sulphate or micronutrients in the nutrient solution also seems to alter a little Phosphate and Potassium concentrations in the tissues.

Table 4: Plant nutrient content in mg/g under the different treatments

Nutrient concentration Treatment	Ca (mg/g DM)	Mg (mg/g DM)	P (mg/g DM)	K (mg/g DM)
Control	15.0	4.7	1.6	14.6
Complete	11.7	4.5	7.0	29.6
"-P"	16.2	4.4	2.0	24.1
"-K"	13.7	5.4	6.9	16.4
"+N"	11.5	3.1	6.4	29.9
"-Ca"	9.2	3.2	5.7	21.9
"-Mg"	13.9	4.2	5.4	26.9
"-S"	8.8	3.7	5.6	28.2
‘’ -micronutrients ‘’	11.3	3.9	5.5	26 .8
Control + OS	19.1	3.3	1.8	18.9
Complete + OS	12.6	2.8	7.2	28.0
"-P" + OS	18.4	3.6	1.5	23.9
"-K" + OS	16.0	3.9	10.1	17.7

Table 5: Plant nutrient content in mg/plant under the different treatments

Nutrient concentration Treatment	Ca mg/plant	Mg mg/plant	P mg/plant	K mg/plant
Control	6.5	2.0	0.7	6.3
Complete	13.7	5.3	8.2	34.6
"-P"	7.0	1.9	0.9	10.4
"-K"	8.9	3.5	4.5	10.7
"+N"	29.0	7.8	16.1	75.3
"-Ca"	10.7	3.7	6.6	25.4
"-Mg"	16.8	5.1	6.5	32.5
"-S"	9.5	4.0	6.0	30.5
« -micronutrients »	13.4	4.6	6.5	31.9
Control + OS	7.8	1.4	0.7	7.7
Complete + OS	13.4	3.0	7.6	29.7
"-P" + OS	8.8	1.7	0.7	11.5
"-K" + OS	6.7	1.6	4.2	7.4

Table 6 shows plant nutrient concentration according to the soil where plants have grown. For calcium and magnesium, results are in accordance with soil chemical analyses, but not necessarily for phosphate and potassium. Nutrients interact inside the plant and can explain those different results. Nutrients were provided in proper concentrations in the nutrient solutions, plant can have taken up according to its needs. Nevertheless when a plant was small, due to a missing nutrient from the nutrient solution and the soil, other nutrients can have been taken up normally, the low plant development can then explain their high concentration.

Table 6: Plant nutrient content under the different soils

Nutrient concentration Soil	Ca (mg/g DM)	Mg (mg/g DM)	P (mg/g DM)	K (mg/g DM)
Gbombtrait	14.9	4.5	5.2	22.7
Bandajuma	14.0	3.8	6.8	26.0
Foya Junction	14.0	4.1	4.7	24.2
Meri Curve	13.5	3.4	5.1	21.3
Kodenbotihnn	12.1	3.2	6.0	24.4

Table 7 reveals the water analyses based on an average of 5 samples taken from the rain water used during the experiment as water for the nutrient solution and for watering the soil. The pH is 6.0 and can have alter a little bit the availability of some nutrients in the nutrient solution as Phosphorus, Calcium, Magnesium and Molybdenum. The pH of the rain water was above all soils' pH, hence soil watering cannot have really changed soil's pH.NO_3concentration was negligible because 1000 times lower than the N concentration in the complete + N solution, as for Cl. CO3, Ca and Mg concentrations were almost zero and cannot have alter the nutrient solution.

Table 7: Characteristics of the water used for the nutrient solution

pH	6.01
CO_3 (mg/l)	0.00
NO_3 (mg/l)	0.50
Cl (mg/l)	0.81
Ca (mg/l)	0.01
Mg (mg/l)	0.01

Discussion

Methodology

Experimental model used

The experiment was done to determine possible nutrient limitations in soils thanks to the double pot technique. Soybean was used in this experiment for its ability to improve soil fertility in Sierra Leone and to benefit subsequent cereal crops, but also for its very nutritious properties for human and animal. Nevertheless the association of the experimental model and soybean did not appear as the best. The model implemented by Jansen in1974 was conclusive with maize as test plant because of its uniform growth and non-tillering characteristics. The non uniform growth of soybean was sometimes particularly visible among plants receiving the same treatment as Figure 17 can show. This results in some significant disparities within the same sample plants, and can alter the relevance of the height and weight averages given in this report. Nevertheless disparities among plants of the same sample may always occur, it is why replicates are used.

Figure 17 : Difference on plant development 25 days after sowing on soybean receiving K omitted treatment.

Indicator for growth

Two indicators for growth were used, the height and weight. Stem height was a non-destructive measure whereas plant weight was not. However, stem height didn't appear as the best growth indicator. Plant weight was a more suitable indicator of soybean growth, results interpretation was then more focus on plant weight.

Nutrient treatment

Plants receiving the complete treatment with an addition of Nitrogen had an impressive development with a dry weight twice as high as plants receiving the complete solution. Increasing N supply enhances growth and may then increase plant demand and so uptake for other nutrients

(Fageria, 2001). For other samples N fixation seemed to not be effective despite the visible good nodulation. Soybean starts to form nodules with some activity after about 8-10 days. However the amount of N fixed probably still remained small at the beginning and the 25 days of the experiment might have been a too short period for an effective catch up. It could have increased over time and plants without N might have caught up with the plants with N. Results would have been then more relevant on a longer experiment, BNF of legumes taking time before being effective. The lower BNF also could be due to the low pH of the soils even if results were not better with oyster shell treatments (see next section for explanations). It is also likely that available N in the soil, which can be lower than the total N which comes out of the soil analyses, had limited soybean growth in combination with a weak biological nitrogen fixation. Consequently it could have been better if, in the experiment, the complete solution had been the complete solution + N, to really assess if nitrogen was a limiting factor for soybean growth, as it seems here.

Deficiencies in Phosphorus were also clear when P was omitted with symptoms on leaves and reduced stem height and weight identical to the control. As mentioned above N supply can increase P uptake, then a plant N deficiency might be a reason for a P deficiency. According to Summer et al. (1986) there is a mutual synergic effect enhancing plant growth and uptake of both elements.

For plants receiving the K omitted treatment dry weight and RGRs were a bit higher than the ones of the control and P omitted treatments. It can be explained by the antagonistic effect of K on Ca, Mg and P absorptions (Fageria 1993). When K was omitted those nutrients could have been taken up more easily from the soil and then allowed a better plant development. The K deficiency can be seen as just a little less limiting in the soil than N and P. Indeed when K was added to nutrient solutions, it could have reduced the taking of some other nutrients leading to a lower development. Plant nutrient concentration are in accordance with this analyse, attesting of a higher Ca, Mg and P contents when K was omitted in the nutrient solution.

For others treatments, omitting Ca, Mg, S or micronutrients did not give different results compared to the full solutions. Those elements did not seem to be missing from the tested soils.

Oyster shell treatment

When pH is under 5.5, as in all the tested soils in the experiment, aluminium concentration can be toxic for the plant. On legumes it can also prohibit nodules formation (Haynes 1998). That is why in the experiment, effects of increasing soil pH were tested on soybean plants. Lime was not available In Sierra Leone and has been replaced by oyster shells powder. According to the results no effect at all can be noticed. However the method and the process of oyster shell addition into the soil might be a reason for this non responsiveness. Studies carried out in Ontario showed that for lime treatments, the smaller the particle size, the faster the lime reaction time for increasing soil pH (with a starting pH of 5.2, two weeks were needed to reach a pH of 6.5 with particle diameter under 0.15mm instead of 20 months for particle with 0.8mm diameter to only reach a pH of 5.5)(Reid, 2006). Thus with size particle above 1.65mm lime addition is seen as non efficient. Now in the present experiment, only oyster shell powder with a diameter less than 2 mm, without going any further in size precision, was used. It could explain the non effect of oyster shell treatment due to the size particles which implies a long reaction time before being effective to increase soil pH. The process of oyster shell treatment, described in Appendix IV, showed an increase in soil pH but used a shaker machine in order to increase the process speed. The pots with oyster shell treatment were not shaked and pH could have remained lower. Hence the oyster shell treatment would have been mix with soil much longer before starting the experiment for being really effective. Nevertheless such practice is only applicable at experimental level and impossible, for now, at agricultural level due to the laboring process to get the oyster shell powder in the requested quantities. Other techniques must be found to increase soil pH in Sierra Leone and really help farmers for enhancing their yields.

Soils and farm management

Soils pH and P content do not allow to make real distinctions between the five tested soils. Optimum pH for soybean growth is between 5.5 and 7.5, in the experiment it ranges from 4.2 for Meri Curve, wish had the second highest biomass production, to 5.2 for Bandajuma, which had the lowest one. Olsen P test also reveals a poor P content for all soils, all less than 4ppm whereas the limit value is 12ppm. These two parameters are surely restricting factors in Sierra Leonan soils, limiting soybean growth. Nevertheless no clear conclusions can be done here on any degree of deficiency due to those very low values.

Bandajuma and Kondebotihun were soils having the lowest results as for weight and height. It seems mainly due to the low percentage of OC (2.5% instead of 2.9% for the three other soils) and N (<0.2 instead of >0.3 for three other soils.) Kondebothihun soil had also a particularly low exchangeable cations content (ECEC of 2.5, 40% lower than the 5 ECEC soil average). Surprisingly those two soils had both the highest P and K plant content but the lowest soil content. The relative plant content of P and K can be high when the plant has remained small due to other limiting factors.

Foya Junction, Meri Curve and Gbomtrait had most of the time the three highest dry weights whatever the missing nutrient was. It shows a better ability for soybean growth as the soil chemical characteristics also showed. Most of the time, Foya Junction had the best soil chemical properties and biomass production. However it should be noticed that the field, where the soil came from, was acquired very recently by the family and as the cropping history attested not so much cultures have been growth up to now. The soil has not been extensively used and consequently exhausted of nutrient. At the opposite, Meri Curve soil was constantly used because of the proximity with the farm house (50m) and its size (1.5ha). As mentioned by Zingore et al. (2007), fields close to the house often receive more fertiliser than outfields. That was typically the case of Meri Curve farm where a 50kg bag of N and 50 kg bag of urea had been applied to the 1.5 ha field, considered as a home field. Those fertilizations have to be taken into account for results of chemical analyses even if the N applied remains 6.5 times under the FAO recommendations for soybean fertilisation in Zimbabwe (250kg/ha instead of 38kg/ha here). Homefields also receive a greater amount of manure allowing to get a better OC and P availability favouring water infiltration and plant growth (Zingore, 2007).

Soybean are grown to enhance soil N content and over year, with crop rotations involving legumes, improvements can be expected at this level. By keeping letting crop residues in fields and avoiding too intensive slash and burn cultivation, soil properties as organic content whish are also limiting would be improved and will give more suitable soils for soybean and crops growth.

Conclusion

Use of the double pot technique allowed a rapid identification of the limiting soil nutrients and can be easily set up. For all tested soils results clearly showed deficiencies in P and deficiencies in K in a lesser extent, expect for Kondebotihun soil. Soils N content are generally quite low too. Except for those three main nutrients, nutrients such as Mg, Ca, S and micronutrients (Cu, Mn, Zn, Fe, B, Mo) are not limiting for soybean growth in the tested soils of the present experiment. Oyster shell as applied in this experiment did not increase plant biomass or height.

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Appendices

Appendix I: Pictures of the experimental model

Experimental model with 25 days soybean plant

Mosquito net as bottom allowing roots to reach the nutrient solution

Appendix II: Nutrients used

	Element	Aspired Concentration (mmol/l for macronutrients; µmol/l for micronutrients)	Form applied
Macronutrients	N	7.5	$Ca(NO_3)_2$, 4 H_2O ; $(NH_4)_2$ SO_4 ; $NaNO_3$
	P	0.5	H_2KO_4P; H_2NaO_4P, 2 H_2O
	K	3.0	KCl ; H_2KO_4P
	Ca	2.5	$CaCl_2$; $Ca(NO_3)_2$, 4 H_2O ; $CaSO_4$, 2 H_2O
	Mg	1.0	$MgSO_4$, 7 H_2O; $MgCO_3$
	S	1.0	$MgSO_4$, 7 H_2O; $CaSO_4$, 2 H_2O ; $(NH_4)_2$ SO_4
Micronutrients	Mn	7.4	$MnSO_4$, H_2O
	Zn	0.96	$ZnSO_4$, 7 H_2O
	Cu	1.04	$CuSO_4$, 5 H_2O
	B	7.13	H_3BO_3
	Mo	0.01	$(NH_4)_6Mo_7O_{24}$, 4 H_2O
	Fe	35mg/L	Fe EDTA

Appendix III: Nutrient solution calculations

- ✓ **Complete Solutions calculation**: (used 3 times for treatment code 2, 9 and 11)

Element	Element Concentration (mmol/l)	Salt	Salt Concentration (mmol/l)	Molar weight (g/mol)	grams/liter (in the solution)	grams/liter (250 x concentrated solution)
Mg	1,0	$MgSO_4$, 7 H_2O	1,0	246,5	0,247	61,63
S	1,0	$MgSO_4$, 7 H_2O	1,0	246,5	already given	/
P	0,5	H_2KO_4P	0,5	136,1	0,068	17,01
Ca	2,5	$CaCl_2$	2,5	111,0	0,278	69,38
K	3,0	H_2KO_4P	0,5	136,1	already given	/
		KCl	2,5	74,6	0,187	46,63

+ Micronutrients (see below) /!\ only used twice, for treatment code 2 and 11

- ✓ **Complete Solutions calculation +N**: (treatment code 3)

Element	Element Concentration (mmol/l)	Salt	Salt Concentration (mmol/l)	Molar weight (g/mol)	grams/liter (in the solution)	grams/liter (250 x concentrated solution)
S	1,0	$(NH_4)_2$ SO_4	1,0	132,1	0,132	33,03
Ca	2,5	$Ca(NO_3)_2$, $4H_2O$	2,5	236,2	0,590	147,59
N	7,5	$(NH_4)_2$ SO_4	2,0	132,1	already given	/
		$Ca(NO_3)_2$, $4H_2O$	5,0	236,2	already given	/
		$NaNO_3$	0,5	85,0	0,043	10,63
Mg	1,0	$MgCO_3$	1,0	84,3	0,084	21,08
P	0,5	H_2NaO_4P, $2H_2O$	0,5	156,0	0,078	19,50
K	3,0	KCl	3,0	74,6	0,224	55,95

+ Micronutrients (see below)

✓ **P-omitted solution calculation:** (used twice for treatment code 4 and 12)

Element	Element Concentration (mmol/l)	Salt	Salt Concentration (mmol/l)	Molar weight (g/mol)	grams/liter (in the solution)	grams/liter (250 x concentrated solution)
Mg	1,0	$MgSO_4$, 7 H_2O	1,0	246,5	0,247	61,63
S	1,0	$MgSO_4$, 7 H_2O	1,0	246,5	already given	/
Ca	2,5	$CaCl_2$	2,5	111,0	0,278	69,38
K	3,0	KCl	3,0	74,6	0,224	55,95

+ Micronutrients (see below)

✓ **K-omitted solution calculation:** (used twice for treatment code 5 and 13)

Element	Element Concentration (mmol/l)	Salt	Salt Concentration (mmol/l)	Molar weight (g/mol)	grams/liter (in the solution)	grams/liter (250 x concentrated solution)
Mg	1,0	$MgSO_4$, 7 H_2O	1,0	246,5	0,247	61,63
S	1,0	$MgSO_4$, 7 H_2O	1,0	246,5	already given	/
Ca	2,5	$CaCl_2$	2,5	111,0	0,278	69,38
P	0,5	H_2NaO_4P, $2H_2O$	0,5	156,0	0,078	19,50

+ Micronutrients (see below)

✓ **Mg-omitted solution calculation:** (treatment code 6)

Element	Element Concentration (mmol/l)	Salt	Salt Concentration (mmol/l)	Molar weight (g/mol)	grams/liter (in the solution)	grams/liter (250 x concentrated solution)
P	0,5	H_2KO_4P	0,5	136,1	0,068	17,01
S	1,0	$CaSO_4$, $2H_2O$	1,0	172,2	0,172	43,05
Ca	2,5	$CaSO_4$, $2H_2O$	1,0	172,2	already given	/
		$CaCl_2$	1,5	111,0	0,167	41,63
K	3,0	H_2KO_4P	0,5	136,1	already given	/
		KCl	2,5	74,6	0,187	46,63

+ Micronutrients (see below)

✓ **S-omitted solution calculation:** (treatment code 7)

Element	Element Concentration (mmol/l)	Salt	Salt Concentration (mmol/l)	Molar weight (g/mol)	grams/liter (in the solution)	grams/liter (250 x concentrated solution)
P	0,5	H_2KO_4P	0,5	136,1	0,068	17,01
K	3,0	H_2KO_4P	0,5	136,1	already given	/
		KCl	2,5	74,6	0,187	46,63
Ca	2,5	$CaCl_2$	2,5	111,0	0,278	69,38
Mg	1,0	$MgCO_3$	1,0	84,3	0,084	21,08

+ Micronutrients (see below)

✓ **Ca-omitted solution calculation:** (treatment code 8)

Element	Element Concentration (mmol/l)	Salt	Salt Concentration (mmol/l)	Molar weight (g/mol)	grams/liter (in the solution)	grams/liter (250 x concentrated solution)
Mg	1,0	$MgSO_4$, 7 H_2O	1,0	246,5	0,247	61,63
S	1,0	$MgSO_4$, 7 H_2O	1,0	246,5	already given	/
P	0,5	H_2KO_4P	0,5	136,1	0,068	17,01
K	3,0	H_2KO_4P	0,5	136,1	already given	/
		KCl	2,5	74,6	0,187	46,63

+ Micronutrients (see below)

✓ **Micronutrients solution calculation:**

Element	Concentration (µmol/l)	Salt	Molar weight (g/mol)	mg/liter (in the solution)	mg/liter (250 x concentrated solution)
Mn	7,50	$MnSO_4$, H_2O	169,0	1,268	316,88
B	7,10	H_3BO_3	61,8	0,439	109,70
Zn	0,96	$ZnSO_4$, $7H_2O$	287,5	0,276	69,00
Cu	1,04	$CuSO_4$, $5H_2O$	249,7	0,260	64,92
Mo	0,01	$(NH_4)_6Mo_7O_{24}$, $4H_2O$	1236,9	0,012	3,09
Fe	35mg/l	Fe EDTA	?	35,00	8750,00

Appendix IV: Oyster shell treatment

African soils are known to be acidic. No treatments at agronomic level are available in Sierra Leone to increase the pH. Lime is neither available. Nevertheless oyster shells treatments can be apply at experimental level, to make the pH as neutral as possible.

The following pictures described the process of graining the oyster shell:

A wooden mortar was used to grain the oyster Shell

Oyster shel in the wooden mortar

Transformation of oyster Shell into powder

Powder of oyster Shell (Ø<2mm)

Then to determine the right amount of oyster shell powder to add into the soil, different pH analyses have been done. Analyses have been carried out on 3 different type of soil, coming from Kambia, Bo and Moyamba Districts. For that, 15 samples (5 for each soil) containing 10g of soil and 25g of distilled water have been prepared. Then in these samples different amount of oyster shell powder have been added, that is to say: 0.0g, 0.5g, 1.0g, 1.5g and 2.0g. After 24 hours of "rest" samples have been shaken by a shaker machine for 20 minutes. Then the pH has been determined by a pH meter. The following table shows the results.

Site	Reference number	Oyster shell treatment	pH
Kambia	1	0.0g/10g of soil	5.04
	2	0.5g/10g of soil	6.82
	3	1.0g/10g of soil	6.86
	4	1.5g/10g of soil	6.90
	5	2.0g/10g of soil	6.91
Bo	6	0.0g/10g of soil	5.25
	7	0.5g/10g of soil	6.89
	8	1.0g/10g of soil	6.84
	9	1.5g/10g of soil	6.86
	10	2.0g/10g of soil	6.90
Moyamba	11	0.0g/10g of soil	5.65
	12	0.5g/10g of soil	6.81
	13	1.0g/10g of soil	6.76
	14	1.5g/10g of soil	6.85
	15	2.0g/10g of soil	6.84

The analyses showed that 0.5g of oyster shell for 10g of soil are sufficient to change the soil pH from, on average, 5.0 to 6.8. Indeed with a more important quantity, results on soil pH are not better. Thus a proportion of 1/20 has been used for pots undergoing the oyster shell treatment.

Appendix V: Total amount of nutrients used for the experiment

Macronutrient stock solutions		
Salt	g for 1L of stock solution	g for 2,5L of stock solution
MgSO4, 7 H2O	493	1232,500
H2KO4P	102,075	255,188
CaCl2	596,625	1491,563
KCl	447,6	1119,000
(NH4)2 SO4	33,025	82,563
Ca(NO3)2, 4H2O	147,59375	368,984
NaNO3	10,625	26,563
MgCO3	42,15	105,375
H2NaO4P, 2H2O	58,5	146,250
CaSO4, 2H2O	43,05	107,625
Fe EDTA	96,25	240,625

Micronutrient stock solution		
Salt	mg for1L of stock solution	mg for 2,5L of stock solution
MnSO4, H2O	3168,75	7921,9
H3BO3	1096,95	2742,4
ZnSO4, 7H2O	690	1725,0
CuSO4, 5H2O	649,22	1623,1
(NH4)6Mo7O24, 4H2O	30,9225	77,3

Appendix VI: Soil collection

The soil was first clear, i.e. all vegetation was removed

Then soil was taken at a depth of 0-20cm

And finally put in bags of 100kg

Overview of the canopy into the different fields:

Field close to Bo

Field close to Moyamba

The field canopy, after almost one year of fallow, was very dense, thus limiting the number of points collection into the different fields.

Appendix VII: Questionnaire

Household:

-How many people live in your household?
-What is the age and the gender of the Household head?
- How much land do you cultivate? (ha or acres)
-What do you produce? (Animal and plant production)
- How many months of the year do you have food from your own farm and how many months of the year do you have to buy food?
-How many people work on your fields? (specific tasks? family labour/hired labour/working groups ?)
-Is there someone in the household who earns cash? Who earns cash? From which activities?
- Which type of livestock do you own and how many.

Field management (field where the soil sample come from):

-What is the area of the field?
-What is the distance from the house?
-For how many years are you using this field?
-How long was the fallow period before you started using this field?

Agricultural practices at the plant production level
-What is the cropping history of the field?
-Do you use crop rotation or intercropping?
-What happens to crop residues?
-Do you use grazing in dry season?
-What were the yields?

Agricultural practices at the soil level
-How do you describe your soil in terms of texture, colour, and moisture holding properties?
-How do you describe the fertility of the soil?
-How do you prepare your land? Did you change methods over the years?
-What fertilizers are used (inorganic fertilizer, manure, leaf litter, compost, spread ant heap)? When and in which quantity?
-Do you have preferences which fertilizer to use? Which crops to receive them? Amongst fields?
-When do you apply inputs in the season?
-Have fertilizers type or quantity changed over the years?

General production
-Have yields changed for the crops you grow? How? Why?
-Do you get advice from somebody how to manage your land?

Apppendix VIII: analysis of the questionnaire

From the five sites where soil samples were taken, only four farmers have been interviewed. Bandajuma's farmer was not present during soil collection. Farm size was highly variable and so was the household size. Farm sizes varied from 3 ha to 15 ha and the household size from 5 to 40 people (table 8). Surface cultivated and household size influenced the period when farmers were food self-sufficient. During the other months, food has to be purchased on local markets. The short food self-sufficiency period of Kondebotihun can be directly linked to the soil chemical properties which reveal a quite bad fertility and can explain low yields reached, even if chemical analyses only reveal the properties of one field. Livestock and activities of certain people of the household can reveal the wealth of the farm. All farms breed chickens, nevertheless they weren't taken into account in the expression of the Tropical Livestock Unit (TLU) because of the low individual conversion factor (0.01) and the difficult estimation of chickens number for farmers. TLU ranged from 0 for Kondebotihun to 0.7 for Gbomtrait. In Meni Curve's farm, nobody in the household was doing trade whereas in the other farms, at least one person, 2 in Gbomtrait farm, were doing trading activities and so earning cash from other activities than farming. Depending on these 2 parameters, livestock possessions and external activities, the household were able or not to hire external labour forces for land cultivation. Nobody was hired for Meni Curve and Kondebotihun farms whereas Foya Junction farm, on the 3ha surface, used 10 to 20 people to work on field, which were twice the household size. Finally in Gbomtrait farm with a surface of 15 ha, 25 out of 40 people in the household worked on the farm and 20 external people were hired when needed, i.e. for land cleaning before sowing, for the sowing itself and for the harvest.

Table 8 : Farm and Household sizes and farm autonomy

Farm	Household size	Cultivated area	Food self-sufficiency from own production	livestock	Labour force	
	(people)	(ha)	(months)	TLU	Household people	external people
Gbomtrait	40	15	5	0,7	25	20
Meni Curve	20	4	3	0,1	10-15	/
Foya Junction	9	3	6	0,1	9	1-10
Kondebotihun	5	4	2	0	4	/

The cultivated crops were quite similar for all the farms, and included cassava, rice, millet, groundnut, soybean, maize, peppers, wheat and sorghum. It is interesting to note that Kondebotihun farm got the most diversified plant production and is led by a young male farmer of 30 years old, who is trying to adapt his production to his soil properties. Other farms were led by woman, older woman for Meni Curve and Foya Junction who were 45 and 56 respectively, and 30 years old for Gbomtrait farm. With a household of 40 people we can guess that in such a farm, the Gbomtrait leader can receive advices from older family members who have been accustomed to cultivate their land over the years. The age and expertise acquired all along the cultivation years may thus be an important factor in the farm management and productivity and then explain the difference in food self-sufficiency with Kondebotihun. Other reasons for low Kondebotihun self-sufficiency may came from no hired labour, resulting in a lower management level or smaller areas planted.

More specifically, where the soil samples have been collected and where soybean has been previously cultivated, field surface and distance from the farm highlight 2 main cases. Foya Junction, Kondebotihun and Gbomtrait fields had a small size ranging from 0.2 to 0.4 ha and were distant from the farm (1 to 1.5 km). At the opposite, Meni Curve farm had a field of 1.5 ha located at 50 m from the house. The proximity of the field resulted in continuous cultivation without any fallow period whereas smaller and distant fields had a 5 years follow period before getting used. The number of years since the family is using the field was related to the age of the farm leader as described in the previous paragraph. For Gbomtrait and Meni Curve field was used for more than 18 years, and only 3 year for Kondebotihun farm. The farmer at Foya Junction acquired the studied field quite recently.

The following table shows the cropping history of each field until the last year of cultivation which was soybean. No proper crop rotations were used by farmers even if they already heard the interesting properties of legumes and tried to include them into crop successions. No intercropping at all was practiced.

Table 9: Field Cropping History

Farm	Cropping History
Gbomtrait	rice/groundnut/cassava/millet/soybean
Meni Curve	maize/potetoes/soybean
Foya Junction	rice/soybean
Kondebotihun	cassava/maize/soybean

For all fields, crop residues were used as manure, being left on the soil after the harvest. Nevertheless the carry-over of nutrients was probably low in this case. During the dry season only Gbomtrait field was used as pasture for livestock. For the others the distance from the farm and the absence of livestock were the main reasons for no grazing. Yield estimation was quite difficult to obtain because the harvest is quickly sold after being collected or directly consumed by the household. It was mainly subsistence farming

Concerning the agricultural practices at the soil level, farmer from Gbomtrait described the soil as black with a lot of moisture, farmer from Meri Curve as a sandy one with few moisture, farmer from Foya Junction as brown even if it depends of the year and then farmer from Kondebotihun described the soil as black with a lot of gravel and clay. All farmers declared their soils as fertile. Generally the soil preparation was the same and was done manually. First, cleaning was done by cutting the grass and burning it and then ploughing was done before sowing. In Gbomtrait and Foya Junction farms additional organic manure was applied at the beginning of the rainy season just after planting. Kondebotihun farm didn’t apply any fertilizer because not owning livestock and because getting inorganic fertilizer was difficult and expensive. In Mericurve field one bag of 50kg of NPK and one of urea were mixed and applied on the field just after sowing, i.e. almost one year before the soil collection for the experiment.