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Crop Water Stress Management

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Master Thesis

EFFECTS OF IMPLEMENTING SIMPLE CROP MANAGEMENT OPTIONS ON SOYBEAN YIELD IN SMALL HOLDER FIELDS IN GHANA

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ABSTRACT

Soybean is an important cash crop for small holders in Northern Ghana to generate income and overcome poverty. Simple crop management options such as (1) seed quality, (2) seedbed preparation, (3) weed control and (4) mineral fertilizer application as P and NPK micro-dosing affect emergence, plant density, TGW, above-ground biomass, seed yield and harvest index. Yield components such as number of side shoots, pods, seeds (filled and unfilled), above-ground biomass, fresh and dry seed yield respond to additional simple crop management options and therefore influence soybean yield. An experiment was conducted on fifteen fields in three communities in Chereponi district, Northern Ghana. Eight treatment combinations and farmers' practice (FP) as control were implemented. As result crop management options significantly influenced emergence. Significantly less plants emerged with P micro-dosing. Plant density at harvest was significantly lower with micro-dosing than without (otherwise same management). The effect of crop management option on above-ground biomass depended on community. Seed yield on additionally weeded subplots was significantly higher than on FP, but there was no significant difference between micro-dosing and FP, probably due to plant density. Harvest index differed significantly between communities but not between treatments. TGW, number of pods, seeds and filled seeds, as well as above-ground biomass and seed yield fresh weight per plant increased with additional crop management option, meaning, best results were found on fertilized subplots. For number of side shoots, pods, above-ground biomass and seed yield fresh weight per plant FP was similar to weed control. Average yields on small holder fields did not even reach Ghana's average soybean yield of 1.8 t per ha, let alone the achievable yield of 2.3 t per ha. Nevertheless, additional crop management options influenced yield components positively, except number of plants per m². Hence, further research should focus on how plant density in combination with fertilizer application affects yield components.

Key words: crop management, Ghana, small holder, soybean (*Glycine max*), yield, yield components

AUTHOR'S DECLARATION

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has been independently prepared, solely with the support of the listed literature references, and that no information has been presented that has not been officially acknowledged.

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Thesis topic: Effects of implementing simple crop management options on soybean yield in small holder fields in Ghana

Semester: 6

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LIST OF ABBREVIATIONS

ANOVA	analysis of variance
AWG	Anoshe Women Group
a.s.l.	above sea level
bl	block
BNF	biological nitrogen fixation
BS	base saturation
CF	coarse fragment
DAS	days after sowing
DW	dry weight
ECEC	effective carbon exchange capacity
FP	farmer's practice
FW	fresh weight
FYM	farm yard manure
GHS	Ghana cedi
GSS	Ghana Statistical Service
HI	harvest index
ICRA	International Centre for development oriented Research in Agriculture
IITA	International Institute of Tropical Agriculture
K	potassium
LSD	least significant difference
MoFA	Ministry of Food and Agriculture
N	nitrogen
NC	North Carolina
OC	organic carbon
P	phosphorus
RP	researcher's plot
S	sulfur
SE	standard error
SSA	Sub-Saharan Africa
TGW	thousand grain weight
trt	treatment
TSP	triple super phosphate

1. INTRODUCTION

Soybean is sometimes called the "chief oilseed crop" of the world for it is the most important source of vegetable oil of the world (Singh & Shivakumar, 2010; Brink & Belay, 2006; Jahaveri & Baudoin, 2001). Even though it was probably introduced to tropical Africa in the 19th century, production has foremost expanded since the 1970s (Brink & Belay, 2006; Jahaveri & Baudoin, 2001) – noting that soybean was only recently introduced to Ghana (Akramov & Malek, 2012).

In Ghana, soybean is mainly cultivated by small holders in the Northern part of Ghana (Akramov & Malek, 2012). The number of soybean farmers in Northeast-Ghana has almost doubled between 2007 and 2009 (ICRA, 2010). A few years earlier this would not have been the case because it was not profitable to cultivate soybean due to insufficient knowledge of soybean production on the farmers' side which led to low yields (ICRA, 2010). However, nowadays both male and female farmers grow soybean in Chereponi district, Northern Region, Ghana, bordering Togo, primarily as a cash crop to generate income (Dogbe *et al.*, 2013).

The agricultural sector in Sub-Saharan Africa still underperforms and the number of poor in Africa doubled in the last two decades from 150 million to 300 million people (The World Bank, 2007). Meanwhile, Ghana had shown a continuous agricultural growth of over three percent between 1990 and 2004 (The World Bank, 2007). Although the contribution of agriculture to recent growth decreased from 42% in 2005 to 22% in 2013. Around 50% of the persons living in the Northern Region of Ghana are still considered to be poor (poverty line = 792.05 GHS) and are involved in agriculture as their main economic activity in this area (GSS, 2014). Ghana has achieved an immense reduction in the level of extreme poverty from 36.5% to 18.2% between 1991 and 2006, nevertheless, certain regions such as the Northern Region still lag behind (MoFA, 2013a).

To achieve high yields of soybean the right „agro-techniques" are of essential importance (Singh, Ram & Aggarwal, 2010). It is particularly important to use inputs wisely and efficiently (Singh *et al.*, 2010). Due to less favorable ecological conditions in the Northern part of Ghana crop management plays a crucial role (Callo-Concha, Gaiser & Ewert, 2012). In addition, soybean depends even more on crop management than other already common crops in Ghana (Mbanya, 2011). Average world soybean yields are 2.25 t per ha but the yield potential in West Africa is even 3 t per ha (Brink & Belay, 2006). The average yield of soybean in Ghana is 1.8 t per ha which still lies below the achievable yield of 2.3 t per ha (MoFA, 2013b). Hence, there's still room to improve and increase soybean yield.

Showing good soybean practices to 4500 farmers in Northeast-Ghana, initiated by SEND-Ghana, a non-governmental organization, the Savanna Agricultural Research Institute, and the International Centre for Soil Fertility and Agricultural Development, was already a good start for more productive soybean cultivation and led even more farmers to produce soybean. But then again more training and knowledge is needed to increase productivity (ICRA, 2010). While soybean usually copes well with rain-fed conditions, makes use of limited moisture and even recovers better than other crops from water deficits during vegetative growth stages (Singh & Shivakumar, 2010; Javaheri & Baudoin, 2001). Yield decreased lately by 8% due to erratic rainfall in Northern Ghana (MoFA, 2013a). There are two critical periods where soybean requires ample water: between sowing and emergence and from pod formation to seed filling (Brink & Belay, 2006; Javaheri & Baudoin, 2001; Pandey, 1987). In addition to that soybean features several benefits: a deep tap-root system loosens the soil; the shedding of leaves provides nutrients; the thick and dense cover conserves soil and moisture; and biological nitrogen fixation (BNF) provides N (Singh & Shivakumar, 2010; Javaheri & Baudoin, 2001).

Soybean is well-suited for a wide range of cropping systems although it does not like water-logged and shallow soils (Singh & Shivakumar, 2010; Brink & Belay, 2006; Javaheri & Baudoin, 2001; Pandey, 1987). Concurrently, cropping system and linked crop management options affect yield of soybean (Javaheri & Baudoin, 2001). Such crop management options are, for instance, tillage, choice of variety, seed cleaning, time of sowing, and depth of sowing, plant population, weed control, mineral fertilizer application, pest control, water management, crop rotation and mixed cropping (Singh *et al.*, 2010; Dugje *et al.*, 2009; Williams, Berglund & Endres, 2004; Javaheri & Baudoin, 2001; Garcia, 1994, Pandey, 1987).

Considering the important role agriculture plays in alleviating poverty in this part of Ghana, an agricultural project was initiated in 2011 (due to run for a period of five years) in the Chereponi district of Northern Region, Ghana by Sabab Lou (a registered German non-profit organization based in Stuttgart). 450 women from five villages are members of Anoshe Women Group (AWG) and execute the project by producing soybean as their main cash crop.

This research investigated particularly the effect of simple crop management options on yield of soybean on small holder fields in North-East Ghana. For the reason that crop management factors have a large influence on crop performance and in the end on soybean yield (Singh & Shivakumar, 2010). Additional simple crop management options influence soybean yield components, and therefore, increase yield of soybean or lead to more regular soybean stands on small-scale fields. Seed sorting, seedbed preparation, weeding and mineral fertilizer application combined lead to highest soybean yields. Results of this experiment aim to make suggestions for improvement of soybean management on farmer's fields (FP).

The objectives of this study were: (1) to determine effects of simple crop management options such as seed quality, seedbed preparation, weed control and mineral mineral fertilizer application as P and NPK micro-dosing on emergence, plant density, above-ground biomass, seed yield and harvest index of soybean and (2) to conduct a simple yield component analysis by determining number of side shoots per plant, number of pods per plant, number of seeds per plant, number of filled and unfilled seeds per plant, above-ground biomass, fresh seed yield and dry seed yield.

2. LITERATURE REVIEW

2.1. SMALL HOLDERS IN GHANA

2.1.1. Introducing small holders

Small holder farming is the “economic backbone” of African agriculture (Mbanya, 2011; Dixon, Tanyeri-Abur & Wattenbach, 2004; Holmén & Hydén, 2001). Small holders are at the focus because they are the largest employment and small-business group of the poor in the world (von Braun, 2005). Many farmers in developing countries are small holders (IITA, 2009; Dixon *et al.*, 2004). In fact, the number of small holders even increased in the last two decades (Dixon *et al.*, 2004). In the Ghanaian agricultural sector more than 80% of the agricultural production is produced on farms smaller than 1 ha (MoFA, 2013a). Since the characteristics of small holders, namely farm size, allocation of resources, the actual farming system and the gender of decision makers, vary from country to country, it is important to look at the farm household in the context of the local surrounding (economy, community, agro-climatic environment) (Dixon *et al.*, 2004).

2.1.2. Small holders in the Northern Region of Ghana

There are strong distinctions between Ghanaian small holders in the various regions of the country and even between male and female farmers (Chamberlin, 2008). Ghana as a whole achieved an immense reduction of extreme poverty from 36.5% to 18.2% between 1991 and 2006, nevertheless, certain regions such as the Northern Region still lag behind (MoFA, 2013a). Northern Ghana is an area that largely depends on farming and has to cope with decreasing yields and crop failures as a result of climate change and land degradation (Laube, Schraven & Awo, 2011).

It was not profitable to grow soybeans in the North-Eastern part of Ghana because of varieties of the shattering type, lacking knowledge about production and poor linkages to traders which resulted in low yields (ICRA, 2010). To overcome these challenges farmers have to be trained to learn best agronomic practices and seed production (ICRA, 2010). Farmers from three areas of North-

Eastern Ghana, namely Chamba, Salaga and Kpandai, exposed to good soybean practices were strengthened tremendously through this approach (ICRA, 2010). The number of farmers producing soybean in North-eastern Ghana has even increased by 197% between 2007 and 2009 (ICRA, 2010).

2.2. CROP MANAGEMENT OPTIONS FOR SOYBEAN

2.2.1. Overview

Environmental factors such as weather or soil type greatly influence the yield potential of soybean, nonetheless, there is still the option to achieve yield gains through management (Haegele & Below, 2013). Sub-Saharan Africa (SSA) may have lower yields than other developing countries due to more difficult agro-ecological conditions (e.g. irregular rainfall, poor soils) and the lack of improved technology (e.g. improved seeds) but the potential to close the yield gap through crop input and crop management options exists (Jayne, Mather & Mghenyi, 2006). In addition, the main benefit of small holders is their labor power (Hazell *et al.*, 2010; Lipton, 2005) leading to an easier adoption of their production patterns and practices to changes in environmental conditions due to climate change (Hazell *et al.*, 2010). Nevertheless, scientific innovation is needed to increase productivity on small-scale farms in neglected areas but in a sustainable way (Lipton, 2005).

In regions where soybean is produced with little technology mean yields differ greatly between farmers and this is often due to different crop management practices (Garcia, 1994). Soybean depends even more on crop management than other already common crops in Ghana (Mbanya, 2011). Consequently, it is important to better understand agricultural practices to improve the livelihoods of small holders in West Africa (González-Estrada *et al.*, 2008). The outcome of a study of different simulated crop management strategies carried out by González-Estrada *et al.* (2008) in the Upper West Region of Ghana was that a farmer would adopt a new management strategy if the economic return was higher.

Important crop management options influencing growth and yield of soybean are tillage, choice of variety, seed cleaning, time of sowing, depth of sowing, plant population, weed control, mineral fertilizer application, pest control, water management, crop rotation/mixed cropping (Singh *et al.*, 2010; Dugje *et al.*, 2009; Williams *et al.*, 2004; Javaheri & Baudoin, 2001; Galerani, 1994; Garcia, 1994).

2.2.2. Tillage

High soybean yields may be realized by tillage, such as ploughing, harrowing (e.g. seedbed preparation) or even no-tillage, but it is also depending on soil texture, weed pressure and production system (Singh *et al.*, 2010). Thus, there are different effects of tillage on soybean yields in different areas (Torres, Saraiva & Galerani, 1994). Because of that it is challenging to recommend a tillage system for a country, region or even a farm (Torres *et al.*, 1994).

Reduced tillage might be one possible way to reverse land degradation and therefore increase the productivity of degrading soils in Africa. However, in many countries of SSA farmers still practice conventional tillage (Kihara *et al.*, 2012). Sowing without ploughing before, also called direct drilling, might have lower traffic intensities but after several years, yields tend to decrease (Botta *et al.*, 2010). In addition, no-ploughing could result in increased weed pressure and soil compaction leading to root diseases (Botta *et al.*, 2010). In a long-term on-farm experiment in Kenya from 2003 to 2007 soybean performed equally well in reduced and conventional tillage systems (Kihara & Njoroge, 2012; Kihara *et al.*, 2012). That means soybean is well-suited for reduced tillage systems, too (Kihara *et al.*, 2012; Jahaveri & Baudoin, 2001). In a field experiment in 2005 and 2006 in the Northern Region of Ghana effects of land preparation methods on crop establishment and grain yield of soybean were investigated (Lawson, Mensah & Yeboah, 2008). According to Lawson *et al.* (2008) for an optimum seed yield soybean could be planted on mounds or ridges after ploughing and harrowing.

2.2.3. Seed quality

Seed is extraordinarily important and the basis to any farming system. It is probably the most important production factor in Ghana and maybe also the cheapest input for crop production (Etwire *et al.*, 2013). The informal seed system is still dominating in SSA. That means farmers themselves select, produce and diffuse the largest quantity of seed. The quality of seed is contributing to food security through yield and product quality. The quality of seed is determined by its genetic properties, the germination rate, seed health and purity of seed. The informal system is slow in improving and adapting crops because it depends on natural ways to create diversity. Furthermore, in the informal system there is often a lack of awareness of crop reproduction systems. Small holders are still highly dependent on informal seed sources due to inadequate access to markets, infrastructure, provision and access to quality seed of improved varieties and lack of genotypes adapted to their production environment (Louwaars & de Boef, 2012). Whereby using adapted soybean varieties for a specific location improves genetic yield potential (Haegele & Below, 2013).

2.2.4. Weed control

One of the most limiting factors in soybean production is weed competition and losses due to weed. Hence, one of the most important management practices for economical soybean production is effective weed control (Mishra, 2010). There are different methods controlling weed: preventive (e.g. cleaning soybean seeds), cultural (e.g. seedbed preparation, crop rotation, planting density), mechanical (e.g. hand hoeing, manual weeding, harrowing) and chemical (e.g. herbicides). Combining all these methods (integrated weed management) is the best approach to control weeds in soybean (Peer *et al.*, 2013; Mishra, 2010; Gazziero *et al.*, 1994). Weed-free fields, especially during the initial 40 to 45 days, tend to have higher soybean yields because weed competition during the early growth stages is high and most critical (Peer *et al.*, 2013; Mishra, 2010; Singh *et al.*, 2010; Abdelhamid & El-Metwally, 2008; Jahaveri & Baudoin, 2001). Regardless of that over 60% of the participants in a study in Northern Ghana did not perform any weed control measure on their soybean fields (Martey *et al*., 2013). Whereas others weeded their soybeans two to three times (Dogbe *et al*., 2013). Jahaveri & Baudoin (2001) state that typically two or three manual weeding are done by small holders. Brink & Belay (2006) say that weeding is usually done one to three times during the first six to 8 weeks. Other methods to control weeds are mechanical or chemical weeding (Singh *et al.*, 2010; Jahaveri & Baudoin, 2001). In a field experiment at the National Research Centre at Shalakan in Egypt during 2006 and 2007 the effect of three pre-emergence herbicides, two hand hoeing treatments and a non-weeded control on growth and yield of soybean was examined. The highest weed depression was measured with two hand hoeing (20 and 40 days after sowing) treatments. Furthermore, it led to the highest number of pods per plant, the highest weight of pods per plant and the highest number of seeds per plant (Abdelhamid & El-Metwally, 2008). In another experiment conducted in Kashmir, India in 2004 and 2005 an integrated treatment of the herbicide pendimethalin and one hand weeding (35 days after sowing) was the most effective and most profitable weed control method for soybean (Peer *et al.*, 2013). Pandey (1987) recommended to hand weed twice – one two weeks after planting and one at flowering.

2.2.5. Soil fertility management

Soybean is well-known for its efficient use of residual fertility. Yet nutrient management highly depends on the soil. Nutrients to improve soybean productivity are mainly phosphorus (P), potassium (K) and sulphur (S). Nitrogen (N) is only necessary if the N status of the soil is low since soybean is able to get N through BNF (Rao & Reddy, 2010; Singh *et al.*, 2010; Jahaveri & Baudoin, 2001; Borkert & Sfredo, 1994). Unlike P deficiency, a problem occurring in most of the acidic tropical soils with low pH and high P-fixation capacity (Rao & Reddy, 2010; Borkert & Sfredo, 1994). S deficiencies most often occur on coarse-textured acidic tropical soils with low organic matter content (Rao & Reddy, 2010; Borkert & Sfredo, 1994). In arid or semi-arid areas boron or aluminium toxicities could negatively affect soybean (Rao & Reddy, 2010). Nutrient application furthermore depends on the cropping system, soil and climatic conditions, yield level, management practices and cultivar (Rao & Reddy, 2010; Borkert & Sfredo, 1994). An optimum nutrient management can increase soybean productivity and is therefore an important crop management option (Rao & Reddy, 2010).

Even though N availability is usually not a problem in soybean, a small starter-dose of N may improve early root and leaf development and thus nodule formation and N fixation (Rao & Reddy, 2010). N fertilizer applied at the right time in combination with suitable planting density may enhance yield and N-use efficiency (Zhang *et al.*, 2013). P fertilizer recommendations depend on soil texture (Rao & Reddy, 2010; Borkert & Sfredo, 1994). There are different P application methods such as drilling, placement or surface broadcast, perhaps influencing P-use efficiency. A P-placement, for instance, is advised for non-intensive cropping systems (Rao & Reddy, 2010). Soybean response to K fertilizer does not only depend on soil-available P and mineralogy but also on other growth-limiting factors like rainfall. But generally soybean responds well to K as experiments have shown (Rao & Reddy, 2010). P and K are recommended to apply before sowing (Singh *et al.*, 2010; Jahaveri & Baudoin, 2001).

In different field experiments on Vertisols in India it was found that the integrated use of organic (e.g. farmyard manure (FYM), poultry manure) and inorganic fertilizers (NPK) bears potential for a productive and sustainable soybean system (Bandyopadhyay *et al.*, 2010; Behera *et al.*, 2007; Bandyopadhyay *et al.*, 2003). In another experiment in India in 2006 even solely FYM increased seed yield and yield components significantly (Maheshbabu *et al.*, 2008).

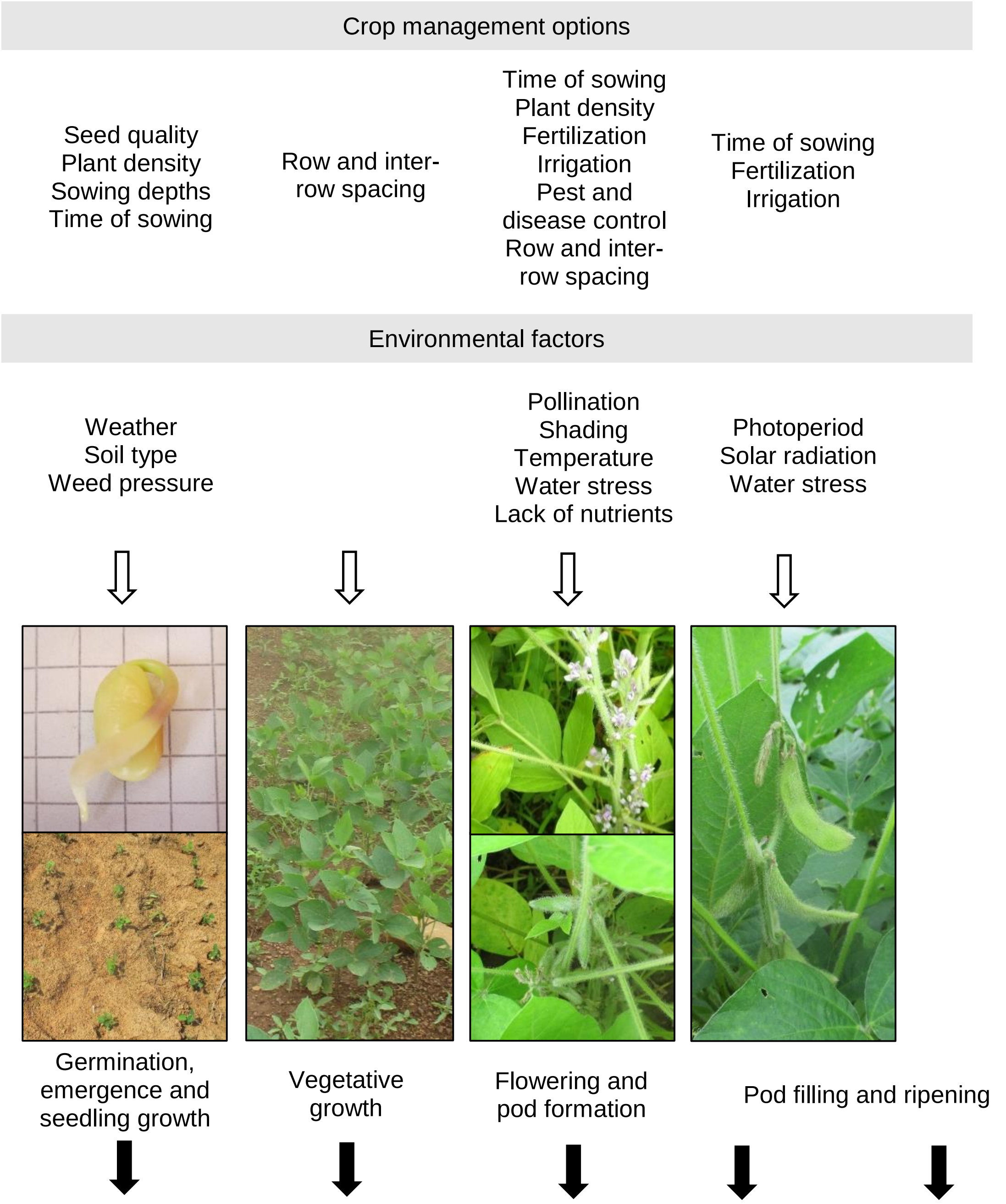
Inoculation significantly increased seed yield of soybean in an experiment in Legon, Ghana. P application at low dose (30 kg/ha) combined with inoculation positively influenced seed yield of two soybean varieties. Hence, for a sustainable agricultural production system biological N fixation might be an addition or substitute to chemical N fertilizers in West Africa (Kumaga & Ofori, 2004).

Ali *et al.* (2013) observed in an experiment in Bangladesh that the highest number of filled pods, number of seeds per pod, 100 seed weight, seed yield and biomass were found with an application of 80 kg P_2O_5 per ha. It should be noted that in a field experiment in India efficiency of P application increased up to a P level of 60 kg P_2O_5 per ha and declined at 80 kg P_2O_5 per ha (Devi *et al*., 2012). In an experiment on the experimental field on the University for Development Studies, Nyankpala, Ghana, Ahiabor *et al.* (2014) found that with increasing P fertilizer rates and inoculation shoot biomass and number of pods per plant was increased. In another field study in Eastern Nigeria where P was applied one week after sowing as triple superphosphate (TSP, 20%) Ikeogu & Nwofia (2013) found that P only influenced number of pods per plant in year and number of seeds per plant in the location. Contrarily, P did not affect seed yield of soybean in a field experiment in South Africa (Mabapa *et al.*, 2010). In a field experiment at Sher-e-Bangla Agricultural University Farm, Bangladesh, number of primary branch per plant increased up to 50 kg P per ha. Increasing number of pods per plant, number of seeds per plant, 1000 seed weight, seed yield and biomass up to 30 kg P per ha were found. There was a positive yield response to S up to 20 kg S per ha. A combination of 30 kg P and 20 kg S per ha led to highest yield of soybean (Akter *et al.*, 2013).

Altogether, to increase crop production in Ghana fertilizer should be used more productively but that is only possible if the fertility status of the soil is known (Fening *et al.*, 2008).

2.3. YIELD COMPONENT ANALYSIS

2.3.1. Soybean yield influenced by different yield components



$$Yield = Plants\ per\ field * Side\ shoots\ per\ plant * Pods\ per\ plant * Seeds\ per\ pod * Seed\ weight$$

Figure 1. Formula for yield consisting of five different yield components in different growth stages influenced by various environmental factors and crop management options.

Yield component analysis is an important technique to examine how yield components influence yield (Kozak & Verma, 2009). Yield components underline the complex system of a plant and its response to crop management and different environmental factors (Pedersen & Lauer, 2004). Important factors affecting yield components are for instance solar radiation (Matthew *et al.*, 2000), light intensity (Liu *et al.*, 2010; Matthew *et al.*, 2000; Pandey, 1987), water stress (Amin, Johan & Hasanuzzaman, 2009; De Souza, Egli & Bruening, 1997; Pandey, 1987; Sionit & Kramer, 1977), drought stress (Kobraei *et al.*, 2011), disease (Yang *et al.*, 1991) or nutrients (Behrouzi *et al.*, 2012; Pandey, 1987). Through positively influencing yield components soybean yield grew. If one yield component is reduced, total yield will also be reduced (Pandey, 1987). This could be pictured using a formula (Lee & Herbek, 2005; Pandey, 1987) consisting of five yield components (Figure 1).

2.3.2. Plants per field

Plants per field are influenced by seed quality and seed rate and are very important to gain high seed yields (Singh *et al.*, 2010) even before sowing but mainly at emergence and seedling growth. An optimum plant population is between 35 to 40 plants per m^2 (Jahaveri & Baudoin, 2001). Since soybean is generally sown in rows, the row spacing and inter-row spacing determines the plant population. Spacing depends on growth habit, sowing time, soil type and other factors. Usually narrow row spacing (< 60 cm) leads to higher soybean yields (Singh *et al.*, 2010; Jahaveri & Baudoin, 2001; Pandey, 1987). Furthermore, wider row spacing requires earlier weeding because early-season crop tolerance to weeds is reduced, thus narrow row spacing is also a practical implementation (Knezevic, Evans & Mainz, 2003) as canopy closes earlier with narrower row spacing (Chauhan & Opeña, 2013).

The right sowing depth is essential for an optimum germination and emergence and thus regular soybean stands (Singh *et al.*, 2010). Javaheri & Baudoin (2001) recommend a sowing depth between 2.5 and 5 cm depending on soil texture. Brink & Belay (2006) state that soybean is sown at a depth of 2 to 5 cm. Lawson *et al.* (2008) found that the optimum sowing depth for Northern Ghana is between 1 and 4 cm. Since the method of sowing is highly influencing the planting density and depth it is also affecting soybean yields (Singh *et al.*, 2010).

Time of sowing has a great influence on the productivity of soybean - sowing too early or too late in the season reduces the yield. That is due to weather conditions during the growing season and characteristics of genotype, soil etc. (Singh *et al.*, 2010). For germination water is essential, furthermore, soil surface must be moist and soft for the seedling to emerge easily (Pandey, 1987).

2.3.3. *Side shoots per plant*

Row spacing and thus plants per field affects number of side shoots per plant during the early growth stages. This was confirmed by an experiment in the Philippines where wider soybean spacing (i.e., 40 x 10 cm) resulted in lowest shoot biomass compared to narrower row spacing (Chauhan & Opeña, 2013).

2.3.4. Pods per plant

Number of side shoots determines the total number of flowers and thus the total number of pods per plant. Number of pods per plant, probably the most important yield component (Pandey, 1987), is especially determined between the beginning of flowering and before full seed stage (Kantolic & Slafer, 2001, Pandey, 1987). Although soybean is mainly auto pollinating, insect pollination, e.g. pollination by honey bee, leads to more pods per plant and more seeds per pod (de O. Milfont *et al.*, 2013; Chiari *et al*., 2005). Abortion of flowers occurs due to poor pollination or limited resource availability (Woodcock, 2012) and also contributes to total number of pods per plant. Another factor influencing number of pods per plant is photosynthesis (Kantolic & Slafer, 2001, Pandey, 1987). Pod number is also affected by cytokinin in the flowers and assimilate availability (Yashima *et al.*, 2005). Shading or defoliation after flowering reduces pod and seed number (Jiang & Egli, 1995). Reasons for pod abortion are high temperatures above 35°C, lack of water and lack of nutrients at early pod filling stage (Pandey, 1987). Water stress during flowering stage, for instance, led to reduced number of pods per plant in an experiment in Iran in 2009 (Kobrae, Shamsi & Rasekhi, 2011). Pedersen & Lauer (2004) found that with earlier planting dates in the season more pods per plant were developed.

2.3.5. Seeds per plant

Pod size determines the number of seeds per pod and thus per plant. Number of seeds per pod is mainly set at the pod filling stage (Pandey, 1987). Seeds per plant just like pods per plant are also dependent on photosynthesis at pod filling (Kantolic & Slafer, 2001, Pandey, 1987). Besides, Kantolic & Slafer (2001) found that seed number is linked to photoperiods and solar radiation. Longer photoperiods lead to a longer time span between the beginning of pod filling to full seed stage and therefore increase seed number (Kantolic & Slafer, 2001). Higher solar radiation increases seed number (Kantolic & Slafer, 2001). A soybean plant is source-limited during the critical time of seed number formation (Egli, 1998). Thagana *et al.* (2013) found that seeds were aborted between 20 days after flowering and before harvest, during the pod filling stage.

A crop management option to increase filled seeds might be mineral fertilizer application as a field experiment in Bangladesh demonstrated. Number of filled seeds per pod increased with increasing level of TSP; number of unfilled seeds per pod decreased with increasing level of TSP (Ali *et al.*, 2013).

Seeds per pod is an important criterion to increase soybean productivity but without knowing how environmental factors influence seed abortion and hence seeds per pod it is difficult to increase soybean productivity (Thagana *et al.*, 2013).

2.3.6. Seed weight (TGW)

Seed filling determines seed weight during ripening (Pandey, 1987). In a quantitative approach, Borrás, Slafer & Otegui (2004) found that soybean seed dry weight responded to increased assimilate availability, especially around mid seed filling, leading to higher seed dry weights. In an experiment in Iran, 2009, water deficit at pod filling stage reduced seed weight (Kobrae, Shamsi & Rasekhi, 2011). However, according to Sionit & Kramer (1977) stress during early pod formation and pod filling is the main factor to reduce seed weight.

2.4. OBSTACLES TO ADOPTION OF PROPOSED CROP MANAGEMENT OPTIONS

Increasing agricultural productivity in small-scale farming is a major goal for national and international organizations especially in village areas that have not yet been impacted (Jirström, Andersson & Djurfeldt, 2011). Though there is skepticism that African small holders can trigger agricultural growth, countries with a major output from small farms, such as Ghana, doubled or more their production from 1980 to 2000 (Wiggins, 2009; Timmer, 2005).

Despite that, to transform small holder farming systems in Northern Ghana adoption of the proposed crop management options in this thesis is necessary since the adoption of new technology is a major factor determining transformation (Conley & Udry, 2001). As mentioned before, average yield of soybean in Ghana is only 1.8 t per ha which is lower than the achievable yield of 2.3 t per ha (MoFA, 2013b). The major reason for such a yield gap is often low adoption of inputs and improved technologies (Ragasa *et al.*, 2013). This could also be the case in Chereponi district, Northern Region, Ghana where the level of adoption of improved crop management options, including row planting, mineral fertilizer application, use of insecticides or rhizobium inoculation, seems to be low, according to Dogbe *et al.* (2013). One factor accounting for poor adoption of soybean technologies in this region was the low level of awareness of soybean technologies such as rhizobium inoculation. Furthermore, soybean is not a traditional staple, therefore farmers were not willing to invest in technologies. Small holders even thought soybean does not need soil amendments and pesticides were considered to be too expensive (Dogbe *et al.*, 2013).

Farm households' decision to adopt agricultural technologies are influenced by their socio-economic situations and institutional effectiveness (Akudugu, Guo & Dadzie, 2012). Akudugu, Guo & Dadzie (2012) found that economic factors, significantly influencing adoption of modern agricultural production technologies in Ghana, are farm size and the expected benefits from adopting modern technologies. Significant social factors include age, level of education and gender. Access to information and extension services were institutional factors that significantly influenced the probability of adoption (Akudugu, Guo & Dadzie, 2012). According to Adeoti (2009) two factors, availability of labour and increases in number of extension visits per year, increase the probability of adoption. Consequently, to increase productivity, adoption of proposed crop management options is inevitable and should be also considered from a socio-economic perspective.

3. MATERIALS & METHODS

3.1. SITE CHARACTERISTICS

The experiment was conducted in three communities (namely Ando, Chere and Nansoni) in Chereponi District in the Northern Region of Ghana during the farming season from June to November 2014. Fifteen fields managed by woman that are members of the Anoshe Women Group (AWG) were selected. Only women willing to participate were chosen by the project manager and the community agents. One criteria was that they had not yet sown all of their soybean field, so that one portion could be left for the experimental plot. The sites in Ando were situated at 10°9.434’N latitude, 0°17.576’E longitude and an altitude of about 170 m above sea level (a.s.l.). The sites in Chere were situated at (1) 10°15.076’N latitude, 0°15.797’E longitude and an altitude of about 167 m a.s.l.; (2) 10°14.496’N latitude, 0°15.397’E longitude and an altitude of about 193 m a.s.l.; and (3), (4), (5) 10°15.535’N latitude, 0°14.865’E longitude and an altitude of about 195 m a.s.l. (Table 1). The sites in Nansoni were situated at 10°11.363’N latitude, 0°11.982’E longitude and an altitude of about 183 m a.s.l. (Table 1).

Table 1. Location of experimental sites.

Community	Site	Latitude	Longitude	Altitude (m a.s.l.)
Nansoni	all	10°11.363’N	0°11.982’E	183.6
Ando	all	10°9.434’N	0°17.576’E	169.7
Chere	(10)	10°15.076’N	0°15.797’E	167.1
	(11)	10°14.496’N	0°15.397’E	192.7
	(12), (13), (14)	10°15.535’N	0°14.865’E	195.4

The region falls within the Guinea Savannah Ecological zone with mean annual rainfall of 1150 mm (MoFA, 2013a). Soils of experimental sites are shallow with loam, sandy loam and silt loam textures, pH between 4.7 and 6, 0.2% to 0.87% organic carbon, 45.75 mmol/kg to 114.41 mmol/kg cation exchange capacity (ECEC), 64.57% to 88.36% base saturation (BS) (Table 1 and Table 2) and an average skeleton content of 50%. Soils of experimental sites in Ando and Chere are Regosols and in Nansoni Plinthosols (Table 2). Soils of the experimental sites are very low in nitrogen (Nt), available phosphorus (Bray P) and even potassium (exchangeable K) but percentage of coarse fragments (CF) is high (Table 2).

Table 2. Textural class and soil type at the different experimental sites in Nansoni, Ando and Chere *.

Community	Site	Soil Depth (cm)	Textural Class	Soil Type	Local Soil Type
Nansoni	all	0-22	sandy loam	Plinthosol	Yabonsheke
		22-50	loam		
		50-79	sandy loam		
		79-100	sandy loam		
Ando	all	0-17	sandy loam	Regosol	Kurungu
		17-39	loam		
Chere	(10)	0-21	sandy loam	Regosol	Kurungu
		21-29	silt loam		
	(11), (12), (13), (14)	ca. 30	loam	Regosol	Kurungu

Table 3. Chemical and physical soil properties at the different experimental sites in Nansoni, Ando and Chere *.

Community	Site	Soil Depth (cm)	OC (%)	Nt (%)	Bray P (mg/kg)	Exch. K	ECEC (mmol/kg)	BS (%)	pH (CaCl)	CF (%)
Nansoni	all	0-22	0.87	0.06	1.28	1.44	64.22	69.37	5.3	59
		22-50	0.45	0.04	0.52	1.62	60.24	76.22	5.0	72
		50-79	0.26	0.02	0.19	1.91	45.75	64.57	4.7	61
		79-100	0.20	0.02	0.19	2.00	51.59	70.93	4.8	62
Ando	all	0-17	0.72	0.07	1.33	2.36	80.07	80.92	5.4	48
		17-39	0.39	0.06	1.10	2.03	114.41	88.36	6.0	86
Chere	(10)	0-21	0.5	0.05	1.35	2.72	70.42	80.85	5.6	28
		21-29	0.31	0.04	0.74	1.29	101.05	84.58	5.0	74
	(11)	ca. 30	0.34	0.03	1.35	1.51	92.56	82.48	5.4	24
	(12), (13), (14)	ca. 30	0.42	0.04	0.94	1.45	82.66	80.02	5.5	29

* Soil samples were analyzed at the Institute of Soil Science and Land Evaluation, University of Hohenheim by Archibong, 2014.

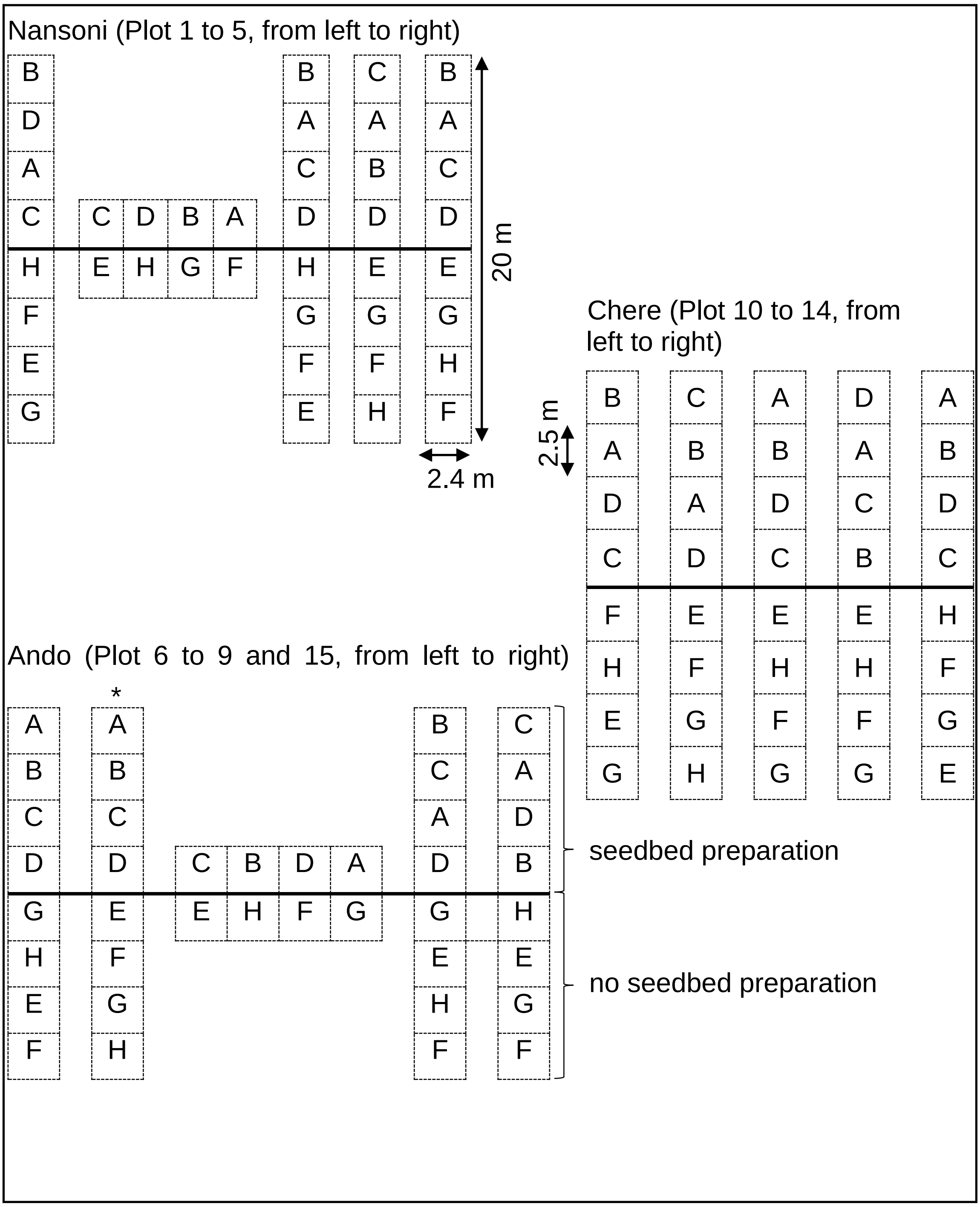


Figure 2. Experimental layout of eight treatments on fifteen plots. The plots were laid in three communities (Nansoni, Ando and Chere) on five different fields per community. Plots measured 2.4 m x 20 m (*) except replicate 7 at Ando 2.4 m x 16 m. Half of the plot was hoed for seedbed preparation. Three squares measured 1 m x 1 m were additionally demarcated on the women's fields as control (farmer's practice).

Treatments consist of A (2), B (2+1), C (2+1+3), D (2+1+3+4), E (1), F (1+3+4), G (1+3), H (4), FP (farmer's fields=control); 1) seed quality, 2) seedbed preparation, 3) weeding and 4) mineral fertilizer application as P and NPK micro-dosing.

3.2. EXPERIMENTAL DESIGN AND AGRONOMIC PRACTICES

Table 4. Eight treatments (Trt) consisting of one to four different treatment factors.

Trt	(1) seed quality	(2) seedbed preparation	(3) weed control	(4) mineral fertilizer application
A				
B				
C				
D				
E				
F				
G				
H				

The experimental plots were demarcated with wooden pegs into eight subplots in which each subplot measured 2.4 m x 2.5 m (one exception: 2.4 m x 2 m) using a 10 m measuring tape. Three squares measured 1 m x 1 m were additionally demarcated on the women's fields as control (farmer's practice). The plots were laid in three communities on five different fields per community (Figure 2). Eight treatment combinations consisting of four treatment factors were implemented (Table 4).

Figure 3. Weighing of impurities.

For the seed quality several parameters were assessed. (a) Percentage impurity: from three seed bags (30 kg) the gross weight was determined. The seed bag was cleared of impurities (sand, stones, wrong seeds, etc.). The weight of impurities was determined and the weight percentage calculated. The mean ±SE weight of impurities determined is 384.3 ±45.8 g which is 1.3%.

(b) Germination tests were conducted. From each unsorted seed lot 3 x 50 seeds, from each seed lot 3 x 50 seeds out of the upper 50% seeds and 3 x 50 sorted seeds were placed in petri-dishes on cotton wool for 4 days. Germinated seeds were counted and germination capacity was calculated (Table 5).

Table 5. Germination capacity of seeds from three different bags (mean ±SE).

Germination capacity	Unsorted seeds	Upper 50% seeds	Sorted seeds
Number of seeds germinated	22.8 ±1.5	30.7 ±2.5	31.3 ±3.8
% of seeds germinated	45.6 ±3.0	61.3 ±5.0	62.7 ±7.7

Upper 50% seeds (seeds ≥ 0.098g, 1000 seed weight of 115.7g), sorted seeds (tilted moving surface).

Figure 4. Germination test, germinated soybeans and flotation technique.

(c) A seed size distribution count was conducted from 3 x 100 seeds from each seed lot and a distribution into seed size classes was performed by determining the seed weight of 3 x 100 single seeds from each seed lot. For the final sowing seeds were sorted by putting seeds on a tilted moving surface, therefore only bigger seeds were used. Seeds in the upper 50% class are ≥ 0.098 g (Table 6).

Table 6. 1000 seed weight of seeds from three different bags (mean).

	Unsorted seeds	Upper 50% seeds
1000 seed weight (g)	97.5	115.7

Upper 50% seeds (seeds ≥ 0.098g), sorted seeds (tilted moving surface).

(d) Percentage of unviable seeds was determined by weighing out 3 x 100 g of seeds. The sample was submerged in a bucket of water and the floating seeds were quickly removed. Sinking seeds were also removed quickly and spread on a sack to dry in the shade (seeds crack if sun-dried). The number of seeds floating and the number of seeds sinking was determined and the percentage calculated. Mean ±SE of floating seeds was 18.9 ±2.7. 1049.2 ±8.7 seeds sunk to the bottom of the bucket. The viability calculated as a percentage of floating seeds and sunken seeds is therefore 98.2%.

The weighing was done on the laboratory balance Sartorius Entris153-1S with a maximum weighing capacity of 150 grams and increments in 0.001 grams graduations (3 decimal places) and a repeatability (std deviation) of +/- 0.001 g.

For the final seed selection pure seeds with as little as possible unviable seeds (flotation test) that have an above average size (tilted moving surface) were selected and sowing density was adjusted according to germination percentage. Sowing density was adjusted using the following formula (Figure 5).

$$Sowing\ density\ \left[\frac{kg}{ha}\right] = \frac{Desired\ plant\ density\ \left[\frac{No.plants}{ha}\right] * 1000\ seed\ weight\ [kg]}{Germination\ capacity\ [\%]}$$

$$Sowing\ density\ \left[\frac{kg}{ha}\right] = \frac{40 * 10^3 * 115.7 * 10^{-3}}{62.7} = 73.8$$

Figure 5. Formula to adjust sowing density (kg/ha) according to germination capacity (%).

This led to a sowing density of 74 kg/ha. Sowing was done by dibbling so number of seeds per hole was calculated based on a plant density of 40 plants per m^2:

$$Sowing\ density\ \left[\frac{No.seeds}{planting\ hole}\right] = \frac{\frac{Sowing\ density\ \left[\frac{kg}{ha}\right]}{1000\ seed\ weight\ [kg]} * 100}{plant\ density\ \left[\frac{No.plants}{ha}\right]}$$

$$Sowing\ density\ \left[\frac{No.seeds}{planting\ hole}\right] = \frac{\left(\frac{73.8}{115.7 * 10^{-3}}\right) * 100}{40 * 10^{3}} = 1.6$$

Figure 6. Formula to adjust sowing density (No. seeds/planting hole) based on plant density of 40 plants per m².

The sowing density (No. seeds/planting hole) would be 1.6 seeds per planting hole which is not possible (Figure 6), thus two seeds per planting hole were sown. All fields were disc-ploughed by a tractor and half of each experimental plot was hoed manually for the seedbed preparation treatment, the other half was not hoed (Figure 7).

During 2014 farming season soybean (*Glycine max*) was sown at the end of June/beginning of July at an average planting depths of 4 cm at two seeds per hole by the dibbling method (Table 10). The distance between rows varied according to field surface and woman dibbling between 17 cm and 40 cm. The distance within rows varied according to field surface and woman dibbling between 9 cm and 19 cm (Table 7).

Mineral fertilizer application was split into two doses (Table 10). The equivalent of 20 kg P_2O_5 per ha was applied as a basal dressing of triple superphosphate (TSP: 46% P_2O_5) and placed below the seed (into planting hole and covered with soil) before sowing. Seeds of 26.16 g were weighed on the laboratory balance Sartorius Entris153-1S per subplot (calculated based on a planting density of 40 plants/m²) and equally distributed in planting holes before planting. TSP was covered with soil before putting the seed. A second dose of NPK fertilizer at a rate of 30 kg N, 30 kg P and 30 kg K per ha was applied as top dressing at late flowering stage and after weeding at the beginning of September. A coke cap was reshaped so that it contained 1.143 g NPK fertilizer, the amount needed per plant. The test-weighing was done on a laboratory scale (Sartorius Entris153-1S).

On the field the reshaped coke cap was used as a distribution device to fetch NPK fertilizer and put it next to the stem (no direct contact) of each plant.

The weeding treatment consisted of two clean weeding procedures (Table 10). First during the exponential vegetative growth stage at the end of July and second shortly before pod filling at late flowering at the beginning of September. Weeding was done manually using a hoe or by hand pulling them. Weeds were put either in between rows or at the side of the experimental plot.

The treatments were laid out in a multi-factorial design with the village as a blocking factor and five replications per village. Soybean plants were grown in the field until maturity was reached under rain-fed conditions.

Farmers' fields were disc-ploughed by a tractor before sowing (Table 10) soybean by the dibbling method. Farmers pre-sorted their soybean seeds before sowing. Broken or shrunken soybean seeds or seeds attacked by insects were not used for sowing. Some farmers did mixed cropping with Guinea corn (*Sorghum bicolor*), cowpea (*Vigna unguiculata*) or okra (*Abelmoschus esculentus*) – others solely grew soybean (Table 8). Whereby Guinea corn was broadcasted before ploughing; cowpea or okra were planted after soybean in between rows. Most of the farmers weeded twice per season (Table 10). Farmers participating in the experiment grew soybeans in rotation with maize (*Zea mays*), fonio (*Digitaria exilis*), Guinea corn (*Sorghum bicolor*), Neri melon (*Citrullus lanatus*), millet (*Pennisetum glaucum*), yam (Dioscorea rotundata), groundnut (*Arachis hypogaea*), Bambara-bean (*Vigna subterranean*) or cowpea (*Vigna unguiculata*) (Table 9).

3.3. OBSERVATIONS AND SAMPLING METHODS

3.3.1. Phenological growth stages

Fields were observed regularly to determine different phenological growth stages such as emergence, onset of flowering, 50% flowering, beginning pod filling and maturity.

Figure 7. Disc-ploughed field and experimental plot – on one half in the back seedbed preparation was done manually using a hoe.

Table 7. Distance between and within rows in three different villages on fifteen fields.

Community	Site	Row spacing (cm)	Inter-row spacing (cm)
Nansoni	(1)	17	17
	(2)	18.5	16
	(3)	20	19
	(4)	25.5	16.5
	(5)	24	16.5
Ando	(6)	40	9.5
	(7)	38	10
	(8)	38	12.5
	(9)	39	9
	(15)	36	13
Chere	(10)	26	13.5
	(11)	27.5	13.5
	(12), (13)	23.5	12
	(14)	22.5	13

Table 8. Cropping system of women participating in the experiment.

Community	Site	Sole, mixed/inter cropping systems
Nansoni	(4)	Soybean
	(1), (2), (3)	Soybean + Guinea corn + cowpea
	(5)	Soybean + cowpea
Ando	(8), (9), (15)	Soybean
	(6)	Soybean + Guinea corn
	(7)	Soybean + okra + cowpea
Chere	(10), (12), (13)	Soybean
	(11), (14)	Soybean + Guinea corn

Table 9. Crop rotation (2011-2014) of experimental sites.

Community	Site	Crop rotation
Nansoni	(1)	Fallow – soybean – fallow – soybean
	(2)	Fallow – groundnut – maize – soybean
	(3)	Yam – millet – Guinea corn – soybean
	(4)	Guinea corn – soybean – maize – soybean
	(5)	Guinea corn – groundnut – cowpea – soybean
Ando	(6), (15)	Fonio – Guinea corn – Neri melon – soybean
	(7)	Guinea corn – maize – millet – soybean
	(8)	Millet – maize – fonio – soybean
	(9)	Bambara-bean – groundnut – soybean – soybean
Chere	(10)	Guinea corn – soybean – cowpea – soybean
	(11)	Maize – maize – maize – soybean
	(12)	Fallow – fallow – Neri melon – soybean
	(13)	Fallow – maize – groundnut – soybean
	(14)	Maize – soybean – maize – soybean

3.3.2. Emergence, plant density, nodulation, above-ground biomass, seed yield, harvest index and TGW (Thousand grain weight)

Number of plants were counted after emergence to determine number of plants emerged.

Number of plants were counted in one square of 1 m x 1 m per subplot and on three squares on the women's fields to estimate plant densities shortly before harvest.

Table 10. Dates of ploughing, sowing, first and second weeding (hoeing), mineral fertilizer application on RP, first and second herbicide application (if applied) in 2014's farming season at fifteen different fields in three communities on FP and RP.

Community		Site	Ploughing	Sowing	1st weeding	2nd weeding	Fertilizer application	1st herbicide application	2nd herbicide application
Nansoni	FP	(1)	23rd June	24th June	6th Aug	-	-	-	-
		(2)	25th June	27th June	6th Aug	-	-	-	-
		(3)	25th June	27th June	6th Aug	-	-	-	-
		(4)	28th June	5th July	25th July	herbicide	-	-	15th Sep
		(5)	28th June	5th July	12th July	-	-	-	-
	RP		see above	7th July	29st July	7th Sep	7th Sep	-	-
Ando	FP	(6)	17th June	28th June	15th Sep	-	-	-	-
		(7)	17th June	28th June	16th Aug	-	-	-	-
		(8)	24th June	unknown	herbicide	2nd Sep	-	5th Aug	-
		(9)	17th June	5th July	15th July	22nd Sep	-	-	-
		(15)	17th June	21st June	5th Aug	21st Sep	-	-	-
	RP		see above	6th July	28st July	6th Sep	6th Sep	-	-
Chere	FP	(10)	26th June	5th July	herbicide	5th Aug	-	6th July	-
		(11)	2nd July	7th July	herbicide	18th Aug	-	1st July	-
		(12)	2nd July	6th July	20th July	17th Sep	-	-	-
		(13)	2nd July	8th July	25th July	10th Aug	-	-	-
	RP	(14)	27th June	5th July	10th Aug	15th Sep	-	-	-
			see above	8th July	30st July	8th Sep	8th Sep	-	-

Shortly before flowering one soybean plant per subplot was carefully dug out and number of nodules was determined. Number of active nodules was determined counting nodules with pink tissue.

At crop maturity at least four soybean plants from two rows in the centre of each subplot were cut and weighed to get the above-ground biomass. If there grew more than one plant per hole, four holes were harvested. On farmer's fields 3 x one m² was harvested to weigh above-ground biomass at harvest and seed yield at harvest. Plants were threshed and seeds were weighed to obtain the seed yield. All the remaining plants per subplot were harvested, threshed and the seeds were weighed. Harvest index was calculated. 3 x 50 seed weight was determined from threshed seeds per subplot and harvest squares on farmer's fields and TGW was calculated.

The weighing was done on an Original Kaiser Back- und Küchenwaage KE 1008 with a maximum weighing capacity of 5000 g and increments in 1 g (decimals only < 1 g, then 1 decimal, e.g. 0.1 g).

3.3.3. Yield component analysis

One plant in the centre of each subplot was harvested and a simplified yield component analysis was conducted. Number of side shoots per plant, number of pods per plant, number of seeds per plant, number of filled and unfilled seeds per plant, above-ground biomass at harvest maturity (almost all leaves dropped, almost all pods are dry, soybeans have their final colour and are dry and hard), fresh seed weight per plant and dry seed weight per plant were determined from all subplots. On farmer's fields 3 x one plant was harvested to determine the same parameters as on the researcher's plots. Seeds were sun-dried and dry seed weights were recorded.

3.4. STATISTICAL ANALYSIS

The multi-factorial experiment was analyzed with a mixed model analysis of variance (ANOVA) (Proc MIXED and Proc GLM, SAS 9.4, SAS Institute, Cary, NC, USA). The blocking factor "community" and treatments "crop management options" were fixed effects in the model.

The effect of eight crop management options grouped in four categories according to treatment factors (Table 11) and FP on number of active nodules, side shoots, pods, seeds, filled and unfilled seeds, above-ground biomass, fresh and dry seed weight per plant, emergence, planting density, above-ground biomass and actual seed yield per m² (actual plant density) of soybean potential seed yield per m² (20 plants per m²) and TGW were analyzed with a randomized mixed model ANOVA and LSD ($p<0.05$) (Proc MIXED, SAS 9.4, SAS Institute, Cary, NC, USA).

Table 11. Treatments grouped according to treatment factors for statistical analysis and comparison of results.

Group		Treatment
(1) seed quality		E
(2) seedbed preparation		A, B
(3) weed control		C, G
(4) P and NPK micro-dosing		D, F, H

In all tests, block (bl) and treatment (trt) were fixed effects in the model. An F-test ($P<0.05$) was conducted to see which factor being tested might be real. If the interaction between bl and trt was significant, means and standard error were calculated for bl x trt interaction. If only the bl effect was significant, means and standard error for each community were calculated. If trt and bl effect were significant, means and standard error for each community and for each crop management option were calculated. If only the trt effect was significant, means and standard error for each crop management option were calculated. Significant differences between bl or trt were shown by letter display (Proc GLM, LSmeans/pdiff lines, SAS 9.4, SAS Institute, Cary, NC, USA).

4. RESULTS

4.1. PHENOLOGICAL GROWTH STAGES

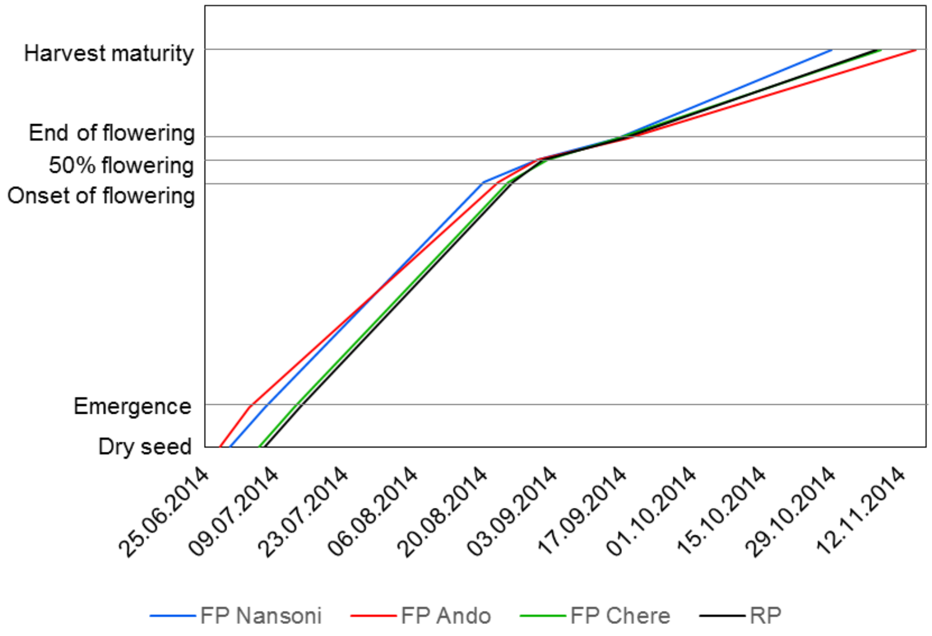


Figure 8. Phenological growth stages on FP and RP (earlier sowing date on FP) in three communities in Ghana.

A great number of AWG farmers sowed their soybeans earlier than soybeans planted on researcher's plot (RP). Soybean plants emerged on average 7 days after sowing (DAS) on RP. Onset of flowering on average was observed at 50 DAS on RP and on farmer's fields (FP) in Ando, 51 DAS in Nansoni and 56 DAS in Chere. 50% flowering was reached at 56 DAS on RP and 61 DAS on average on FP. End of flowering was reached 72 DAS on RP and on FP in Chere, 78 DAS in Nansoni and 82 DAS in Ando. Soybeans were harvested 117 DAS on RP and on FP in Nansoni 122 DAS, in Ando 128 DAS and in Chere 120 DAS. Soybeans were harvested during the same time on FP and RP (Figure 8).

4.2. EMERGENCE AND PLANT DENSITY

4.2.1. Emergence

Communities and crop management options significantly influenced emergence of soybean ($P<0.05$) (Figure 12). Plant establishment in Nansoni was significantly lower than in Ando and Chere. There was no significant difference in number of plants emerged between Ando and Chere (Table 14).

Table 12. Analysis of variance of the response of different parameters of soybean to block (bl), treatment (trt) and block x treatment interaction (bl x trt).

	Emergence	Plant density	Active nodules	Above-ground biomass	Actual yield	Potential yield	HI	TGW
bl	5.11 *0.0073 **	1.46 *0.2369 n.s.*	3.46 *0.0341 **	5.49 *0.0051 **	14.18 *<0.0001 **	34.94 *<0.0001 **	42.27 *<0.0001 **	4.35 *0.0147 **
trt	10.91 *<0.0001 **	6.92 *<0.0001 **	1.48 *0.2116 n.s.*	6.19 *0.0001 **	5.46 *0.0004 **	8.29 *<0.0001 **	1.85 *0.1225 n.s.*	37.19 *<0.0001 **
bl x trt	1.23 *0.2860 n.s.*	1.03 *0.4143 n.s.*	0.7 *0.6948 n.s.*	3.35 *0.0016 **	1.72 *0.0994 n.s.*	0.77 *0.6258 n.s.*	0.78 *0.6225 n.s.*	1.05 *0.4018 n.s.*

Emergence (No. of plants per m²), Plant density (No. of plants per m²), Active nodules (No. of active nodules per plant), Above-ground biomass (g/m²) and Actual yield (g/m²) with actual plant density, Potential yield (g/m²) assuming homogeneous plant density of 20 plants per m², HI (harvest index) and TGW (g).

Results from the mixed model analysis of variance (F-test) and statistical significance (* P<0.05 or *n.s.* not significant) for each parameter are shown.

Table 13. Analysis of variance of the response of yield parameters of single soybean plants to block (bl), treatment (trt) and block x treatment interaction (bl x trt).

	Side shoots	Pods	Seeds	Filled seeds	Unfilled seeds	Above-ground biomass	Seed yield FW	Seed yield DW	HI
bl	2.29 *0.1051 n.s.*	3.33 *0.0389 **	1.27 *0.2849 n.s.*	2.17 *0.1179 n.s.*	4.38 *0.0143 **	3.68 *0.0279 **	1.67 *0.1918 n.s.*	0.59 *0.5549 n.s.*	0.85 *0.4286 n.s.*
trt	8.17 *<0.0001 **	28.35 *<0.0001 **	37.72 *<0.0001 **	38.12 *<0.0001 **	1.22 *0.3037 n.s.*	17.83 *<0.0001 **	15.79 *<0.0001 **	1.57 *0.1853 n.s.*	2.03 *0.0936 n.s.*
bl x trt	0.95 *0.4763 n.s.*	1.04 *0.4097 n.s.*	1.30 *0.2496 n.s.*	1.01 *0.4301 n.s.*	1.32 *0.2365 n.s.*	1.05 *0.4025 n.s.*	1.57 *0.1390 n.s.*	0.76 *0.6411 n.s.*	0.91 *0.5088 n.s.*

Side shoots (No. of side shoots per plant), Pods (No. of pods per plant), Seeds (No. of seeds per plant), Filled seeds (No. of filled seeds per plant), Unfilled seeds (No. of unfilled seeds per plant), Above-ground biomass (g/plant), Seed yield FW (fresh weight in g/plant), Seed yield DW (dry weight in g/plant), HI (harvest index).

Results from the mixed model analysis of variance (F-test) and statistical significance (* P<0.05 or *n.s.* not significant) for each yield component are shown.

Number of plants emerged differed significantly between FP and seed quality (E), seedbed preparation (A, B) and mineral fertilizer application as P and NPK micro-dosage (D, F, H). With crop management option of seed quality and seedbed preparation significantly more plants emerged than on FP. Mineral fertilizer application significantly reduced emergence of plants in comparison with FP. Emergence with weed control and under FP did not significantly differ (Figure 9).

4.2.2. Plant density

Crop management options significantly affected plant density of soybean in three communities in Ghana (P<0.05) (Table 12). The plant density on subplots with weed control but without mineral fertilizer application (C and G) was significantly

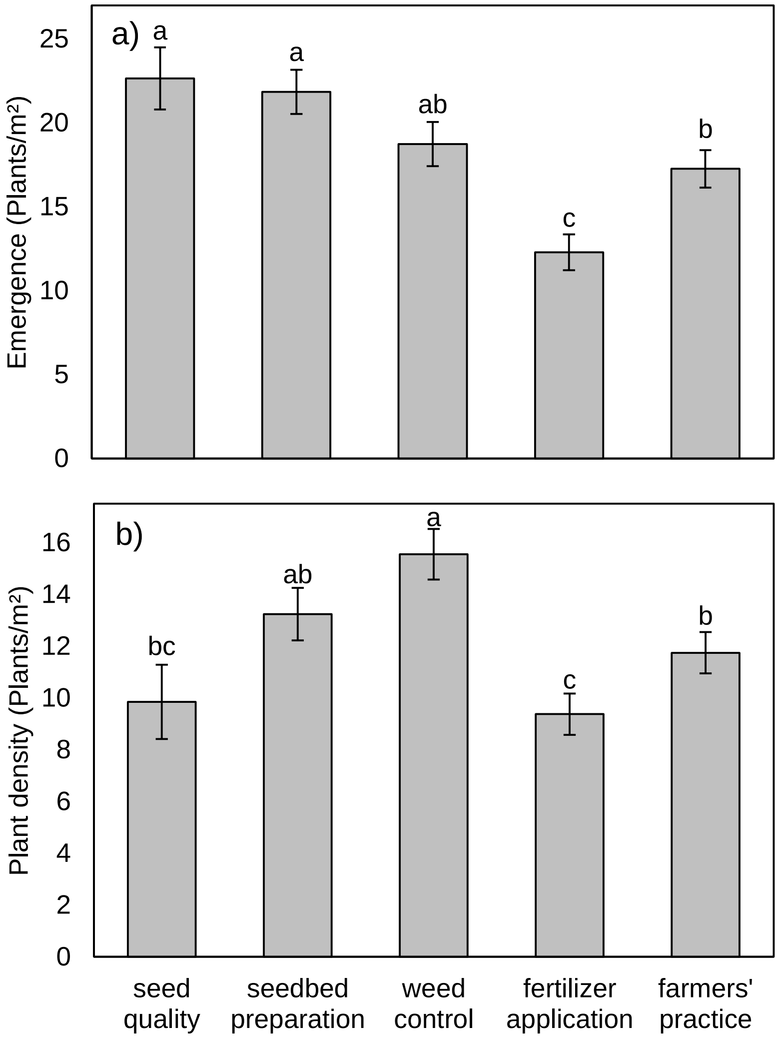


Figure 9. Effect of four different management options and farmer's practice in three communities in Ghana on a) emergence and b) plant density at harvest of soybean.
Bars show the mean number of plants/m² ± 1 standard error, different letters indicate significant effects (P<0.05) of management option on No. of plants.

higher than on FP. Mineral fertilizer application (D, F, H) resulted in significant lower plant densities than on FP. Plant densities on subplots with seed quality only (E) and were significantly lower than with weed control (C, G). There was no significant difference of plant density between seedbed preparation, weed control and FP, as well as, between seed quality, seedbed preparation and FP (Figure 9).

4.3. NODULATION

Crop management options did not significantly ($P<0.05$) influence number of active nodules per plant (Table 12) but there was a significant block effect of community on number of active nodules per plant (Table 15). Highest number of active nodules per plant was found in Chere, lowest in Ando. Number of active nodules was significantly different from each other in these two communities. Nansoni's number of active nodules was in between Ando's and Chere's.

Figure 10. Nodulation of soybean plant at beginning of flowering.

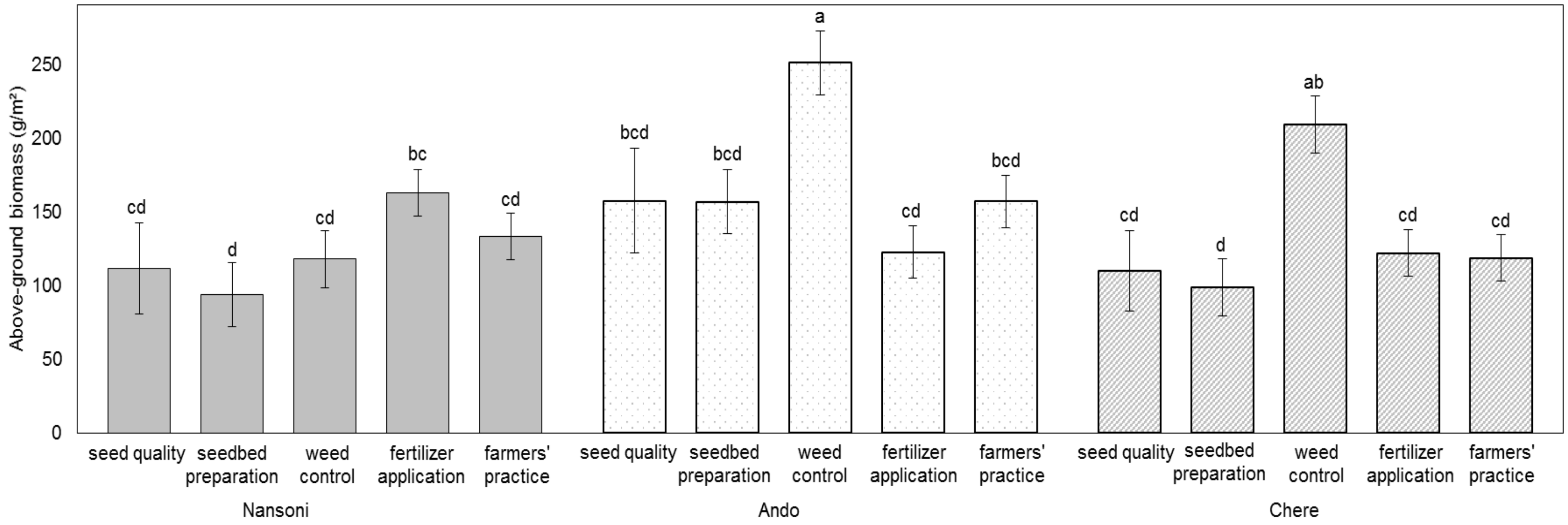


Figure 11. Effect of four different crop management options and farmer's practice on above-ground biomass (g/m²) of soybean in three communities (Nansoni, Ando and Chere) in Ghana.

Bars show the mean above-ground biomass ± 1 standard error, different letters indicate significant effects ($P<0.05$) of crop management option on above-ground biomass (g/m²). The following additional pairs are significantly different: Chere weed control and Ando famers' practice; Ando farmers' practice and Chere seedbed preparation; Ando farmers' practice and Nansoni seedbed preparation; Ando seedbed preparation and Chere seedbed preparation; Ando seedbed preparation and Nansoni seedbed preparation.

4.4. YIELD RESPONSE TO FOUR SIMPLE CROP MANAGEMENT OPTIONS IN COMPARISON WITH FP (BASED ON TWO ROWS)

4.4.1. Above-ground biomass

Communities and treatment had a significant effect on actual (real plant density) and potential (assuming homogeneous plant density of 20 plants per m²) weight above-ground biomass of soybean (P<0.05). There was an interaction effect between community and treatment that means treatment effects depend on community (Table 12).

Above-ground biomass on FP in different communities did not significantly differ from each other. Neither did above-ground biomass on plots with seed quality treatment (E) and mineral fertilizer application (D, F, H). Above-ground biomass on subplots with seedbed preparation (A, B) was significantly higher in Ando than in Nansoni and Chere. Weed control (C, G) in Nansoni resulted in significantly lower above-ground biomass than in Ando and Chere. In Ando and Chere weed control led to significantly higher above-ground biomass than all the other treatments (Figure 11).

Table 14. Effect of three communities (block) on emergence, actual and potential yield and HI (mean ± 1 SE).

	Emergence	Actual yield	Potential yield	HI
Nansoni	15.9 ±1.0 ^{b}	62.2 ±3.9 ^{b}	108.3 ±9.0 ^{b}	0.52 ±0.02 ^{c}
Ando	19.6 ±1.1 ^{a}	115.2 ±4.4 ^{a}	188.6 ±10.0 ^{a}	0.72 ±0.03 ^{b}
Chere	20.2 ±1.0 ^{a}	110.7 ±3.9 ^{a}	206.5 ±8.4 ^{a}	0.83 ±0.02 ^{a}

Emergence (No. of plants per m²), Actual yield (g/m²) with actual plant density, Potential yield (g/m²) assuming homogeneous plant density of 20 plants per m², HI (harvest index)
Significant differences (P<0.05) within a column are shown by different letters.

4.4.2. Seed yield

Communities and crop management options significantly influenced actual (real plant density) and potential (assuming homogeneous plant density of 20 plants per m²) seed yield of soybean (P<0.05) (Table 12).

Nansoni's actual and potential seed yield was significantly lower than Ando's and Chere's. There was no significant difference in Ando and Chere (Table 14).

Table 15. Effect of three communities (block) on active nodules, pods, unfilled seeds, above-ground biomass based on a single plant and TGW (mean ± 1 SE).

	Active nodules	Pods	Unfilled seeds	Above-ground biomass	TGW
Nansoni	4.5 ±0.95 [ab]	53 ±5.8 [b]	14 ±1.3 [a]	5.3 ±0.31 [a]	181.2 ±0.02 [b]
Ando	3.5 ±1.05 [b]	62 ±6.5 [ab]	11 ±1.4 [ab]	4.6 ±0.34 [ab]	193.4 ±0.03 [a]
Chere	7.0 ±0.95 [a]	74 ±5.8 [a]	9 ±1.3 [b]	4.2 ±0.30 [b]	196.9 ±0.02 [a]

Active nodules (No. of active nodules per plant), Pods (No. of pods per plant), Unfilled seeds (No. of unfilled seeds per plant, Above-ground biomass (g/m²), TGW (g) Significant differences (P<0.05) within a column are shown by different letters.

Crop management options with weed control (C, G) resulted in significant higher actual seed yields in comparison with FP and all other treatments. Actual seed yield of subplots with seed quality (E), seedbed preparation (A, B), mineral fertilizer application (D, F, H) and FP did not significantly differ from each other (Figure 12).

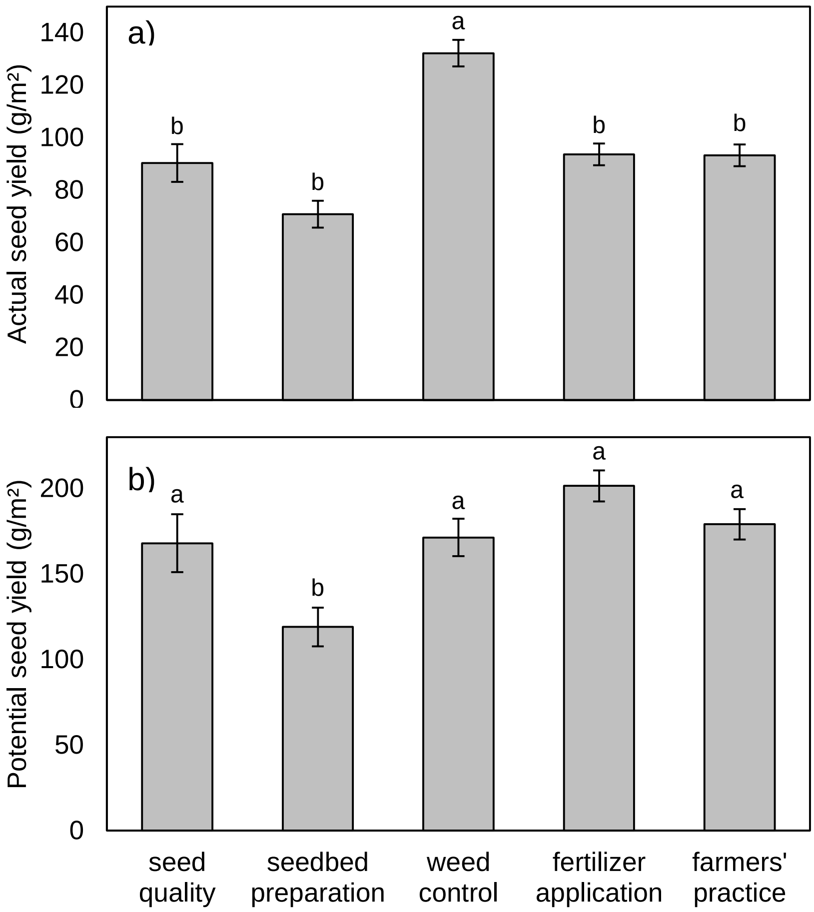


Figure 12. Effect of four different management options and famers' practice in three communities in Ghana on a) actual seed yield with actual plant density and b) potential seed yield assuming homogeneous plant density of 20 plants per m².
Bars show the mean seed yield ± 1 standard error, different letters indicate significant effects (P<0.05) of management option on seed yield.

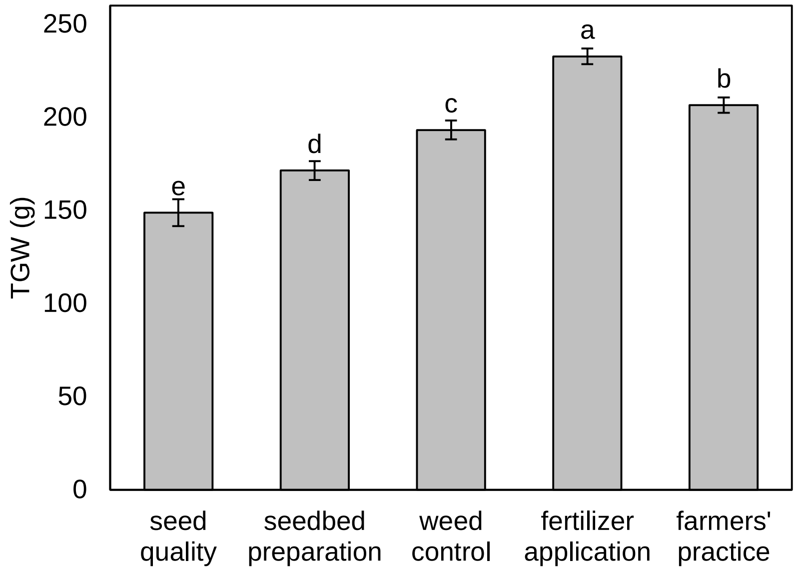


Figure 13. Effect of four different management options and farmers' practice in three communities in Ghana on TGW.
Bars show the mean TGW ± 1 standard error, different letters indicate significant effects (P<0.05) of management option on TGW.

Assuming a plant density of 20 plants per m², all crop management options, except seedbed preparation (A, B) and FP did not significantly differ from each other. Seedbed preparation resulted in significant lower potential seed yield compared with all the other crop management options and FP (Figure 12).

4.4.3. Harvest index (HI)

HI of soybean in Ghana was affected by three different communities (P<0.05) (Table 12). Nansoni's HI is significantly lower than Ando's, Ando's is significantly lower than Chere's (Table 14).

4.4.4. Thousand grain weight (TGW)

Communities and crop management options significantly influenced TGW of soybean (Table 12). TGW in Nansoni was significantly lower than TGW in Ando and Chere. There was no significant difference between Ando and Chere (Table 14).

All four crop management options were significantly different from each other and from FP. Mineral fertilizer application led to highest TGW, followed by FP, weed control, seedbed preparation and last seed quality (Figure 13).

4.5. RESPONSE OF YIELD COMPONENTS TO FOUR SIMPLE CROP MANAGEMENT OPTIONS IN COMPARISON WITH FP (BASED ON SINGLE PLANTS)

4.5.1. Number of side shoots per soybean plant

Crop management had a significant effect on number of side shoots per plant (Table 13). With mineral fertilizer application (D, F, H) number of side shoots was about 25% higher than FP. With seedbed preparation (A, B) number of side shoots was almost 25% lower than FP. There was no significant difference between FP and seed quality (E) and weed control (C, G), although number of side shoots increased with additional crop management option, except seed quality which was not significantly different from seedbed preparation and weed control. Significantly highest number of side shoots per plant was found with mineral fertilizer application (Figure 14).

4.5.2. Number of pods per soybean plant

Both, treatment and community significantly influenced number of pods per plant (Table 13). Number of pods per plant were significantly different between Nansoni and Chere. Number of pods per plant was significantly higher in Chere than in Nansoni (Table 15). Crop management options with mineral fertilizer application (D, F, H) had significantly more pods, almost 80%. There was no significant difference of pods per plant between seedbed preparation (A, B) and weed control (C, G), as well as weed control and FP. Seed quality (E) had almost 70% lower number of pods than FP and was significantly different from FP. Seedbed preparation led to almost 50% less pods per plant than FP. Number of pods per plants increased with additional crop management option from seed quality to seedbed preparation to weed control to mineral fertilizer application. Number of pods per plant on FP was similar to weed control (Figure 14).

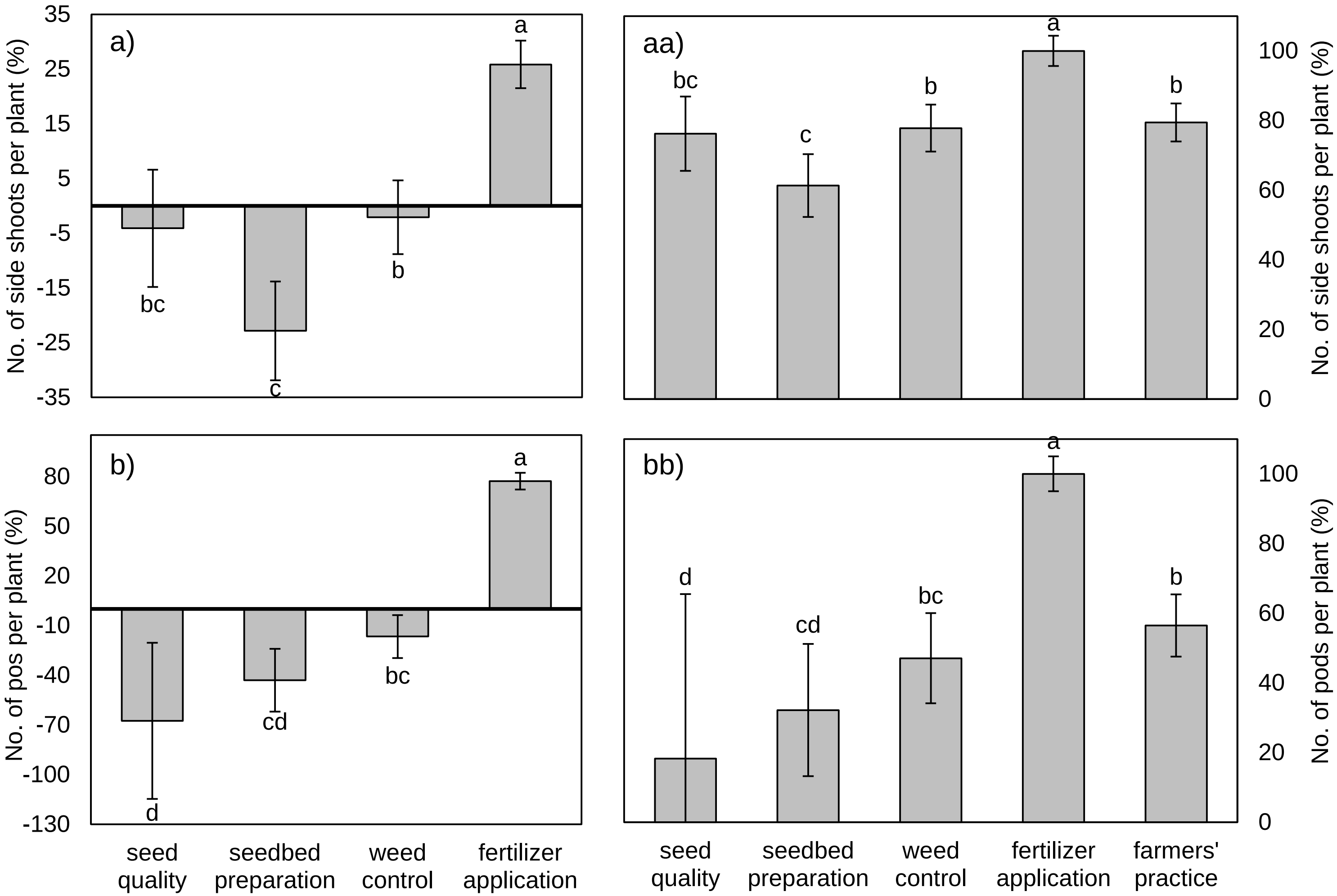


Figure 14. Effects of four different management options and farmers' practice in three communities in Ghana on side shoots per plant in comparison with a) FP=0 and aa) best performance=100% and pods per plant in comparison with b) FP=0 and bb) best performance=100%.

Bars show the mean as a percentage based on FP or the best performance ±SE (%), different letters indicate significant effects (P<0.05) of management option on yield components per plant.

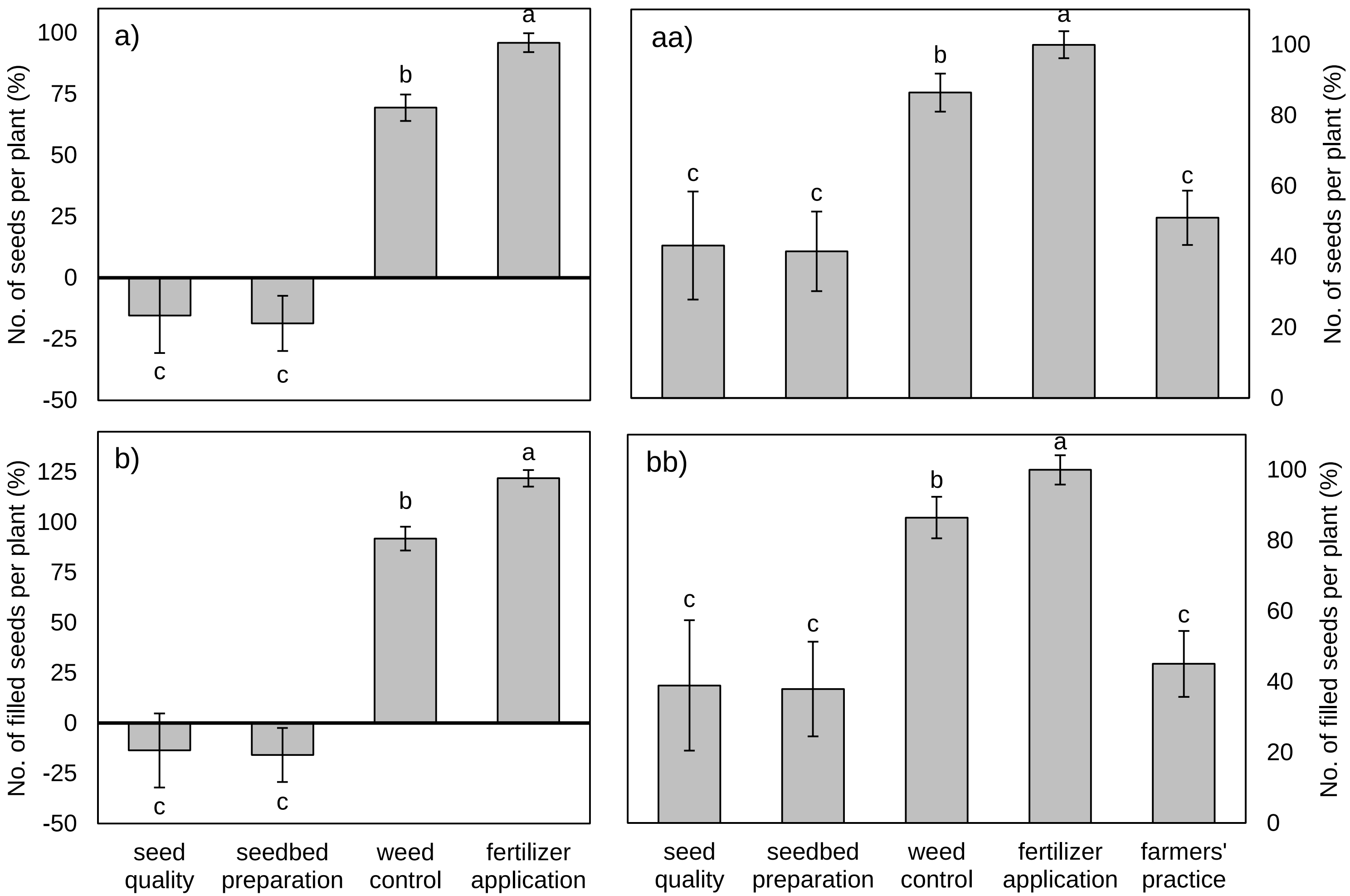


Figure 15. Effects of four different management options and farmers' practice in three communities in Ghana on seeds per plant in comparison with a) FP=0 and aa) best performance=100% and filled seeds per plant in comparison with b) FP=0 and bb) best performance=100%.

Bars show the mean as a percentage based on FP or the best performance ±SE (%), different letters indicate significant effects (P<0.05) of management option on yield components per plant.

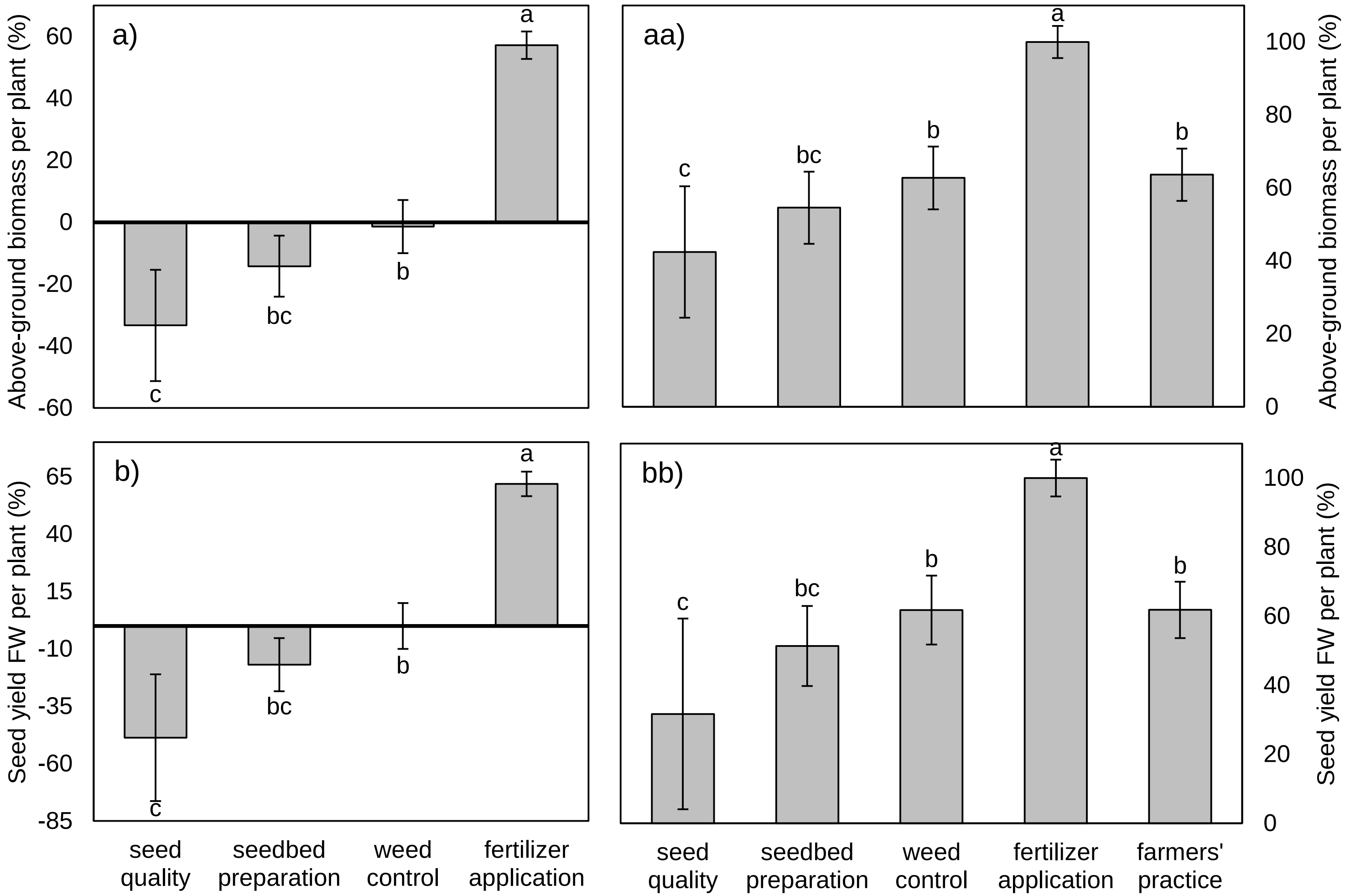


Figure 16. Effects of four different management options and farmers’ practice in three communities in Ghana on above-ground biomass per plant in comparison with a) FP=0 and aa) best performance=100% and seed yield FW per plant in comparison with b) FP=0 and bb) best performance=100%.

Bars show the mean as a percentage based on FP or the best performance ±SE (%), different letters indicate significant effects ($P<0.05$) of management option on yield components per plant.

4.5.3. Number of seeds, filled seeds and unfilled seeds per soybean plant

Number of seeds and number of filled seeds per soybean plant were significantly affected by treatment. There was a significant effect of block on number of unfilled seeds per soybean plant (Table 13). Number of unfilled seeds in Nansoni was significantly higher than in Chere. There was no significant difference in number of unfilled seeds per plant between Nansoni and Ando, neither between Ando and Chere (Table 15).

There was no significant difference between number of seeds and filled seeds per plant with seed quality (E), seedbed preparation (A, B) and FP. Weed control resulted in significantly higher number of seeds and filled seeds per plant than seed quality, seedbed preparation and FP. With weed control about 60% more seeds and about 80% more filled seeds per plant than on FP were found. Mineral fertilizer application (D, F, H) led to the highest number of seeds and filled seeds per plant and was significantly different from all other crop management options and FP. Mineral fertilizer application had around 90% more seeds and more than 100% more filled seeds per plant than FP (Figure 15).

4.5.4. Above-ground biomass per m² (based on single plants)

Communities and treatment had a significant effect on above-ground biomass of soybean ($P<0.05$) (Table 13). Above-ground biomass in Nansoni was significantly higher than in Chere. There was no significant difference between Nansoni and Ando or Ando and Chere (Table 15). Above-ground biomass with mineral fertilizer application (D, F, H) was significantly higher (more than 50%) than above-ground biomass with other crop management options. There was no significant difference shown between above-ground biomass of A, E, G and H. With treatment A, E and G above-ground biomass was lower than on FP. There was no significant difference of above-ground biomass between seedbed preparation (A, B), weed control (C, G) and FP. Above-ground biomass with seed quality (E) significantly differed from weed control, mineral fertilizer application and FP and it was around 30% lower than FP. Additional crop management options led to higher above-ground biomass (Figure 16).

4.5.5. Seed yield fresh weight and dry weight per m² (based on single plants)

Crop management options significantly influenced seed yield fresh weight (FW) but there was no significant effect ($P<0.05$) of either community or crop management option on seed yield dry weight (DW) (Table 13). There was no significant difference of seed yield FW between seedbed preparation (A, B), weed control (C, G) and FP, neither between seed quality (E) and seedbed preparation. Seed quality had significantly lower seed yield FW than FP, approximately 50%. Mineral fertilizer application (D, F, H) led to significantly highest seed yield FW and was more than 50% higher than FP (Figure 16).

4.5.6. Harvest index (HI) (based on single plants)

Neither community nor crop management option had a significant effect ($P<0.05$) on harvest index of soybean single plants (Table 13).

5. DISCUSSION

5.1. SIMPLE CROP MANAGEMENT OPTIONS FOR SOYBEAN

5.1.1. Overview

Crop management is an option to increase soybean yield (Haegele & Below, 2013). This study demonstrated that implementing simple crop management options such as seed sorting, seedbed preparation, weeding and P and NPK micro-fertilization affects soybean yield components and soybean yield on small holder fields in Ghana. Furthermore, this study came up with additional ideas of improving management on small holder fields in Ghana such as row spacing, planting date, method of mineral fertilizer application, crop rotation, etc. Further research is necessary to evaluate these ideas.

5.1.2. Tillage and seedbed preparation

Seedbed preparation may increase soybean yield, although this is dependent on soil texture, weed pressure and production system (Singh *et al.*, 2010). Even though ploughing was done at all experimental sites it could have had an effect on soybean yields since soil types varied on the experimental sites (Torres *et al.*, 1994). For emergence, seed yield, HI and TGW an effect of community on yield or yield parameters was found. Moreover, ploughing was sometimes problematic because of shallow soil and high CF (coarse fragments) (Table 3).

Summarized, seedbed preparation had no significant effect on emergence and plant density, neither was there a significant difference of soybean seed yield and above-ground biomass between seedbed preparation and no seedbed preparation if all other crop management options were the same (seed quality and seedbed preparation) (Figure 9). Yet, taking the TGW into account, comparing the same crop management options, additional seedbed preparation resulted in significantly higher TGW (Figure 13).

Seedbed preparation led to significantly lower number of side shoots and pods per plant (Figure 14) but similar number of seeds and filled seeds per plant (Figure 15), as well as above-ground biomass and seed yield FW (based on single plant) (Figure 16) comparing seedbed preparation and FP. Setting aside direct effects of seedbed preparation on yield, seedbed preparation must still be taken into consideration with respect to the effect of regular soybean stands on yield. Supposing sowing could be done in more organized rows if seedbed preparation was done. As a consequence row spacing and sowing depth could be done in a more homogeneous way even with the actual sowing method (dibbling) which had an effect on soybean stands and therefore eventually on soybean yields (compare actual yield with potential yield assuming homogeneous plant density, Figure 12) (Singh *et al.*, 2010). Additionally, weeding or mineral fertilizer application would also be easier with seedbed preparation.

5.1.3. Seed quality and seed sorting

Seed is the basis to every farming system (Etwire *et al.*, 2013). Farmers of AWG used their own seed or bought seed from another soybean farmer in the market (informal seed system) similar to most of the farmers in SSA (Louwaars & de Boef, 2012). Seed sorted for this experiment was also accessed through an informal seed source, thus variety and genetic yield potential is unknown (Haegele & Below, 2013; Louwaars & de Boef, 2012). There was no significant difference of emergence between seed quality, seedbed preparation and weed control. However, emergence with seed quality was significantly higher than FP (Figure 9). This was probably more due to different sowing dates on RP and FP or even varying sowing depths (Table 10) (Singh *et al.*, 2010), even though germination capacity of sorted seeds was only around 60% (Table 5). Using soybean varieties that are adapted to Chereponi district, Northern Ghana could result in higher soybean yields due to improved genetic yield potential (Haegele & Below, 2013). TSP micro-dosing at sowing led to significantly lower emergence compared with seed quality (Figure 9) probably due to application method of TSP (see chapter 5.1.5).

5.1.4. Weed control

Effective weed control is one of the most important management practices to achieve high soybean yields (Mishra, 2010). At this point it is important to mention that different persons weeded differently and that might have affected weeding treatments and in the end yield parameters. On one plot at Ando weeding was even started without informing the researcher.

Weeded subplots had significantly higher plant densities at harvest than non-weeded subplots (except seedbed preparation) (Figure 9). Highest above-ground biomass was found on weeded subplots (Figure 11). Actual seed yields on weeded subplots were significantly higher than on FP and all other subplots (Figure 12). Looking at the potential seed yield (20 plants per m²), FP resulted in the same yield level as weeded and fertilized subplots (Figure 12).

TGWs were significantly higher with additionally weeded than non-weeded subplots but significantly lower than FP (Figure 13).

There was no significant effect of weeding on number of side shoots in comparison with FP nor on pods and above-ground biomass (based on single-plant) (Figure 14, Figure 16). Nevertheless, with additional weeding to seedbed preparation and seed sorting, number of pods per plant was slightly higher. This might be attributed to the date of first weeding for the initial 40 to 45 days are most critical in terms of weed competition and yield (Peer *et al.*, 2013; Mishra, 2010; Singh *et al.*, 2010; Abdelhamid & El-Metwally, 2008; Jahaveri & Baudoin, 2001). Besides, many women did not do the first weeding in the initial 40 to 45 days (Table 10).

Weed control led to significantly higher number of seeds and filled seeds per plant than on FP, seed quality and seedbed preparation (Figure 15). This might be due to the second weeding at the end of flowering beginning of pod. Number of seeds are connected to photosynthesis, especially between flowering and full seed stages (Kantolic & Slafer, 2001) and even to removal of weeds that shaded soybean plants and reduced seed number (Jiang & Egli, 1995). Even so it is difficult to know which environmental factors influenced seed number or seed abortion (Thagana *et al.*, 2013).

Seed yield FW (based on single plant) was not significantly different between weeded subplots and FP. This could be attributed to differences in number of pods and number of seeds and filled seeds per plant.

There are different methods of weed control, for example preventive, cultural, mechanical and chemical weed control. Combining all these methods is according to previous work the best approach to control weeds in soybean (Peer *et al.*, 2013; Mishra, 2010; Gazziero *et al.*, 1994). In this study only cultural (seedbed preparation) and mechanical (2 x hand hoeing) methods were tested but previous researchers found different effects of chemical, mechanical or combined weed control methods on weed depression, number of pods per plant and number of seed per plant (Peer *et al.*, 2013; Abdelhamid & El-Metwally, 2008). Therefore, studies on number, timing and method of weed control are necessary to find best adapted weeding strategy to this specific area in Northern Ghana.

I want to add that even if non-weeded plots resulted in similar yields, mineral fertilizer application and harvest would be a problem because at times weeds were bushier and taller than soybean plants and it was difficult to find soybean plants within weeds.

5.1.5. Mineral fertilizer application as micro-dosing (1st dose TSP and 2nd dose NPK) and nutrient management

Nutrient management highly depends on the soil (Rao & Reddy, 2010; Singh *et al.*, 2010; Jahaveri & Baudoin, 2001; Borkert & Sfredo, 1994). Soils differed between communities participating in this experiment. N status of soils on experimental sites was very low, so N fertilization is necessary to improve soybean productivity (Rao & Reddy, 2010; Singh *et al.*, 2010; Jahaveri & Baudoin, 2001; Borkert & Sfredo, 1994). According to Singh & Rachie (1987) soybean is sensitive to soil infertility, thus, nutrient management is even more important.

Crop rotation differed between sites (Table 9) partly explaining differences in soybean yield between sites. Crop rotation is a good entry point for further research, especially when looking at soil fertility (Galerani, 1994). With an appropriate crop sequence soil surface is protected, macro-pores are stabilized, diseases are controlled and organic matter (crop residues) is added to the system (Galerani, 1994). Crop rotation depends on region, economic return and preference of famers (Galerani, 1994), consequently further research for this specific area in Northern Ghana is necessary.

Emergence on all fertilized subplots was significantly lower than on non-fertilized plots and FP (Figure 9, Table 16), probably as a result of mineral fertilizer application method but also sowing date and water availability (Singh *et al.*, 2010). It did not rain for several days after sowing on RP and one of the critical periods where soybean needs ample water is between sowing and emergence (Brink & Belay, 2006; Javaheri & Baudoin, 2001; Pandey, 1987). Plant density at harvest reflected emergence of fertilized subplots but the difference to FP and non-fertilized subplots was not significant, except weed control (Figure 9). Another reason for lower emergence on fertilized subplots could be that TSP was applied into the planting hole and thus some seedlings might have been burned even though TSP was covered with soil before sowing. A better method of placing P would be for example to create a 3 cm deep furrow 5 cm away from the soybean row and add appropriate dosage of P (Pandey, 1987).

There was no significant difference of actual above-ground biomass between crop management options at Nansoni, except seedbed preparation and mineral fertilizer application were significantly different from each other (Figure 11). At Ando fertilized subplots produced less biomass than non-fertilized subplots with otherwise same crop management options. At Ando and Chere above-ground biomass with mineral fertilizer application was significantly lower than weed control (Figure 11). Hence weed control had more influence on above-ground biomass than mineral fertilizer application. Plant density might be one factor influencing above-ground biomass. Denser soybean stands (narrow row spacing) seem to produce more biomass that supports previous studies on the effect of row spacing on soybean yields (Singh *et al.*, 2010; Jahaveri & Baudoin, 2001).

There was no significant difference in actual seed yield between fertilized subplots and FP. Assuming a potential seed yield with a homogeneous plant density of 20 plants per m² seed yield on subplots with mineral fertilizer application did only significantly differ from seedbed preparation (Figure 12, Table 16). If plant density increased, it might lead to higher seed yields. Nevertheless, higher plant density could also affect yield components negatively and lead to lower yields because more plants would compete for water and nutrients.

TGW was significantly higher with mineral fertilizer application (Figure 13). Similar observations were made in previous studies in Bangladesh (Akter *et al.*, 2013; Ali *et al.*, 2013).

Previous studies have suggested that increasing P fertilizer rates increased shoot biomass (Ahiabor *et al.*, 2014; Akter *et al.*, 2013) and indeed additional mineral fertilizer application had a significant effect on number of side shoots per plant (Figure 14). Number of side shoots under mineral fertilizer application was significantly higher than on FP and under all other crop management options.

Number of pods per plant was significantly higher on fertilized subplots than on FP (Figure 14). These findings support previous research in Bangladesh, Ghana and Nigeria (Ahiabor *et al.*, 2014; Akter *et al.*, 2013; Ali *et al.*, 2013; Ikeogu & Nwofia, 2013). Although P was applied at a low level (20 kg P_2O_5 per ha), the response of pods per plant to P application was about 75% higher in comparison with FP (Figure 14). One reason might be that nutrient management highly depends on the soil (Rao & Reddy, 2010; Singh *et al.*, 2010; Jahaveri & Baudoin, 2001; Borkert & Sfredo, 1994) and soils of experimental sites are very low in P (Table 3). Looking at treatment H, mineral fertilizer application without any other crop management option, lower number of pods were found. An explanation could be high weed pressure and therefore shading after flowering leading to reduced pod numbers (Egli, 1998) but also competition for nutrients and water – thus two other factors influencing number of pods per plant (Behrouzi *et al.*, 2012; Kobraei *et al.*, 2011; Amin *et al.*, 2009; Yashima *et al.*, 2005; De Souza, Egli & Bruening, 1997).

Significant differences of seeds and filled seeds were recorded between mineral fertilizer application and weed control (Figure 15). Ali *et al.* (2013) observed in an experiment in Bangladesh that number of filled seeds per pod increased with increasing level of TSP and number of unfilled seeds per pod decreased with increasing level of TSP. The highest number of seeds per pod was found with an application of 80 kg P_2O_5 per ha (Ali *et al.*, 2013). In a study in Bangladesh increasing number of seeds per plant were found up to 30 kg P per ha (Akter *et al.*, 2013). Contrarily, this research evaluated only two levels of TSP, namely 0 and 20 kg P_2O_5 per ha. A tendency to increased seeds per plant with increasing level of TSP was found but to prove this assumption for this area further research on different levels of TSP is necessary. Opposing to Ali *et al.* (2013) crop management option had no significant effect on number of unfilled seeds per plant (Table 13). It should be taken into account that selecting unfilled seeds is rather subjective and may differ from person to person counting filled and unfilled seeds. The effect of NPK application at late flowering, beginning of pod filling might have also had an effect on number of seeds per plant but it is difficult to know which environmental factors influence seed abortion and therefore seeds per plant (Thagana *et al.*, 2013).

Seeds per plant had been slightly increased with additional mineral fertilizer but also number of pods per plant was higher on fertilized plots than on non-fertilized plots meaning number of seeds per pod might not have been increased.

Above-ground biomass (based on single plants) was significantly higher (> 50%) on fertilized subplots than on non-fertilized subplots and FP (Figure 16). In a previous study in Bangladesh biomass also increased up to 30 kg P per ha (Akter *et al.*, 2013).

Seed yield FW (based on single plants) was significantly higher (> 50% in comparison with FP) on fertilized than on non-fertilized subplots (Figure 16). According to this, similar results were recorded in previous studies (Akter *et al*., 2013; Ali *et al.*, 2013).

To increase crop production mineral fertilizer application should be used in a productive but sustainable way, hence the fertility status of the soil must be known (Fening *et al.*, 2008). This was done in another discipline within this project (Table 3), however, future research could elaborate on that aspect. Furthermore, S deficiencies most often occur on coarse-textured acidic tropical soils with low organic matter content (Rao & Reddy, 2010; Borkert & Sfredo, 1994). It is true that soils on experimental sites were shallow, coarse-textured and very low in organic matter but they were not acidic (Table 3), despite that S deficiency might be a problem worthy to investigate in further studies. Soybean plants on non-fertilized subplots were sometimes pale-green which could be either an indication for N or S deficiency, although, symptoms for S deficiency are not as easily recognized (Borkert & Sfredo, 1994). Differences in colour between fertilized and non-fertilized subplots and soil chemical properties (Table 3) rather indicate N deficiencies on non-fertilized subplots. Different plant heights on fertilized and non-fertilized plots could be accounted to P enhanced nodulation among other parameters such as growth and yield parameters (Kumaga & Ofori, 2004). Other symptoms found on leaflets are yellowish borders around the edges, perhaps indicating K deficiencies, and slow growth without weeding and micro-dosing, perhaps indicating P deficiencies (Borkert & Sfredo, 1994). It would be necessary to do further research in the direction of omission trials to diagnose deficient nutrients.

Table 16. Effect of four different crop management options and farmer's practice in three communities in Ghana on emergence, plant density, actual seed yield (actual plant density) and potential seed yield (assuming homogeneous plant density of 20 plants per m^2).

	Emergence (No./m^2)	Plant density (No./m^2)	Actual seed yield (t/ha)	Potential seed yield (t/ha)
Seed quality	23^{a}	10^{bc}	0.9^{b}	1.7^{a}
Seedbed preparation	22^{a}	13^{ab}	0.7^{b}	1.2^{b}
Weed control	19^{ab}	16^{a}	1.3^{a}	1.7^{a}
Fertilizer application	12^{c}	9^{c}	0.9^{b}	2.0^{a}
FP	17^{b}	12^{b}	0.9	1.8^{a}

Table shows the mean, different letters indicate significant effects ($P<0.05$) of crop management option on yield parameters in the same column.

Figure 17. Soybean leaves fading in colour becoming pale green and RP showing healthy green soybean on fertilized plot and yellowish, pale green soybean on non-fertilized plot.

In this experiment NPK was applied at the end of flowering/beginning of pod filling growth stage unlike recommendations found in literature suggested (Zhang *et al.*, 2013; Rao & Reddy, 2010; Singh *et al.*, 2010; Jahaveri & Baudoin, 2001) where it is recommended to apply N, P and K before sowing as a starter dose. Furthermore, the calculation of the amount of NPK per plant was based on average plant densities and the amount applied was rather inhomogeneous due to different grain sizes of mineral fertilizer and the tool (re-shaped coke cap) used to apply NPK leading to an unequal distribution of NPK. A similar problem occurred at TSP application, for the reason that TSP grains were of various sizes and shapes and TSP was weighed per subplot not per planting hole, the amount of P per plant might have differed from plant to plant – for further experiments I recommend to grind fertilizer grains into powder to measure it more equally.

Neither organic matter nor inoculation was part of this experiment but observations on fields, where those soil fertility crop management options were practiced, appeared to be more productive. The integrated use of organic and inorganic fertilizer bears potential for a productive and sustainable system (Bandyopadhyay *et al.*, 2010; Behera *et al.*, 2007; Bandyopadhyay *et al.*, 2003) and could even increase seed yield and yield components (Maheshabu *et al.*, 2008), particularly in this environment with very low soil organic matter contents (Table 3). Inoculation might increase soybean yield, as an experiment in Northern Ghana showed where soybean yield was correlated to percent of N fixed (Kombiok & Buah, 2013). Number of active nodules on experimental sites was very low (Table 15). Chere was the community with highest number of active nodules but even then mean number of active nodules was 7 (Table 15). Inoculation might rise number of active nodules but further research is required. Especially in combination with P, inoculation could improve soybean yield and it could be even an addition or substitute to chemical N fertilizers (Kumaga & Ofori, 2004). A study in Pakistan confirms that a combination of inoculation of soybean seeds before sowing and application of P at sowing led to higher soybean yield through increased nitrogenase activity of nodules (Fatima, Zia & Chaudhary, 2007). BNF is a dynamic process influenced by several factors including P availability and nitrogen fixing bacteria. If one of these factors is not available optimum BNF is not assured (Fatima, Zia & Chaudhary, 2007). Hence, P micro-dosing at sowing is most effective when nitrogen fixing bacteria are present and nodulation takes place. Otherwise a starter dose of NPK should be considered, even though further research needs to focus on that.

From literature it is not clear whether a more efficient nodule system or N fertilizer application is recommended to gain higher soybean yields. Possibly, with increasing inputs of N fertilizer, N from BNF decreases in most environments. Nevertheless, many times, N derived from BNF is not sufficient to replace N export from the field (Salvagiotti *et al.*, 2008). A study in Sri Lanka compared crop performance of soybean under use of inoculants and N fertilizer. The study showed how important BNF is, even under mineral fertilizer application in the Tropics (Seneviratne, Van Holm & Ekanayake, 2000). According to Salvagiotti *et al.* (2008) BNF is the most sustainable and cheapest source of N. The response to additional N is not always given but sometimes there is a response, hence, more research is required (Salvagiotti *et al.*, 2008).

5.2. ACTUAL YIELD AND YIELD POTENTIAL OF SOYBEAN

According to literature (Brink & Belay, 2006) yield potential of soybean in West Africa is 3 t/ha but in spite of that average soybean yields in Ghana (1.8 t/ha) do not even reach the achievable soybean yield of 2.3 t/ha (MoFA, 2013b). Looking at average soybean seed yield of this experiment, none of the treatments achieved average yields of 1.8 t/ha – but ranging from 0.7 to 1.3 t/ha (Table 16). This is probably the case due to low plant densities between only 7 and 16 plants per m² (Table 16) which is not up to half of the optimum plant population of 35 to 40 plants per m² (Jahaveri & Baudoin, 2001). Sowing density in this experiment was calculated to aim at 40 plants per m², nevertheless, on account of poor emergence (plant densities between 12 and 23 plants per m²) (Table 16) and probably weather conditions this aim was not reached. Assuming an optimum plant population of 40 plants per m², yields might have been much higher. With a plant population of 20 plants per m² yields might have been higher and fertilized subplots would have led to better yields (Figure 12). On the other hand, with higher plant population competition for nutrients and water increases. These two factors, nutrients and water, are already limiting due to shallow, coarse-fragmented, nutrient-poor soils (Table 3) and might negatively influence yield with increasing plant density. It would be interesting to investigate the effect of higher plant density and micro-dosing on soybean yield components and yield.

Seed yield DW was not significantly affected neither by treatment nor by community (Table 13) – probably due to weighing on an ordinary kitchen scale, hence all values were rather inaccurate and different moisture contents after drying. Neither HI based on rows nor HI based on single plants was significantly influenced by treatment (Table 13). HI is defined as soybean seed yield (DW) divided by above-ground biomass. If now both, above-ground biomass and seed yield, responded similarly to different crop management options, it would result in similar HI. Another influencing factor might be moisture content of soybeans at weighing.

Damage caused by insects, pest and diseases might also hinder to reach achievable soybean yields (Figure 18). Soybean plants at some sites were even almost completely destroyed by insects (most often by ants). Further research needs to focus on identification of pest and diseases in soybean and control as it is also an important crop management option (Singh *et al.*, 2010; Dugje *et al.*, 2009; Williams *et al.*, 2004; Jahaveri & Baudoin, 2001; Garcia, 1994, Pandey, 1987)).

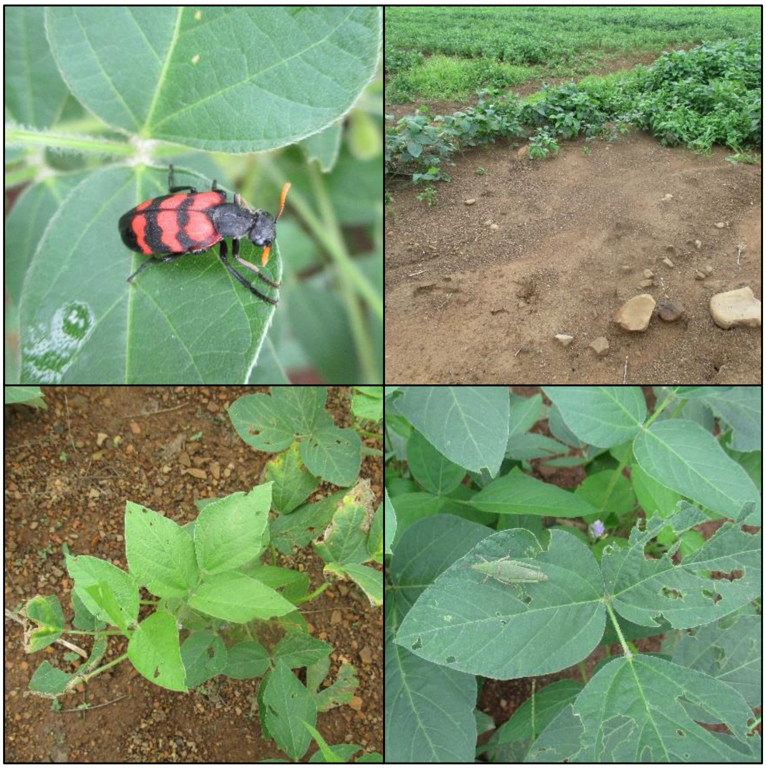


Figure 18. Soybean plants and part of soybean stands damaged by pests or diseases.

5.3. THE ECONOMIC ASPECT

Soybean is mainly grown as a cash crop in Chereponi district, Northern Region, Ghana to generate income (Dogbe *et al.*, 2013). Therefore, it is important to consider the economic aspect of different crop management options. Mineral fertilizer application had additional costs in terms of input but also labour and led to Gross Losses. Aiming for higher and homogeneous plant densities could lead to Gross Profits, however, this still has to be investigated. Seedbed preparation only and even farmer's practice led to a Gross Loss (Adjogo, Wahl, Baffour & Archibong, 2015). Concluding, that without increasing actual soybean seed yields micro-dosing will not be economically worthwhile. As long as the economic return is not higher with a new management strategy, farmers would not adopt it (González-Estrada *et al.*, 2008). For this reason alternative cash crops for this region, such as sesame which could be a suitable crop for this region (Ofosuhene & Yeboah-Badu, 2010), and cotton which is already established in this area, should be taken into consideration and could already be included in further experiments.

6. CONCLUSION

Simple crop management options help to achieve higher soybean yields on small-scale fields in Ghana by increasing yield components such as number of plants per m², number of side shoots, pods and seeds per plant, TGW or above-ground biomass. With additional crop management options soybean yield components increase, and thus, lead to higher soybean yield.

Small holders in Northern Ghana grow soybean as a cash crop to generate income and overcome poverty, still, average yields on their fields did not even reach Ghana's average soybean yield of 1.8 t per ha, let alone the achievable yield of 2.3 t per ha, neither did the best result on RP. Nevertheless, additional crop management options influenced yield components positively, except number of plants per m², meaning that the actual yield with all crop management options was lower than on non-fertilized subplots with otherwise same management. Emergence on fertilized subplots was significantly lower than on all other subplots, possibly due to the method of TSP application but also sowing date, and leading to significantly lower plant densities on fertilized subplots compared with non-fertilized subplots with otherwise same management. Differences in plant density at harvest could also be accounted to irregular row and inter-row spacing and in addition damage through insects, pests or diseases.

Despite the fact that plant density was lower on fertilized subplots, it is not clear if higher plant densities result in higher soybean yields. Furthermore, it would be interesting to know whether number of seeds per pod was influenced by NPK application and if other nutrients were lacking and how organic matter or inoculation could positively affect yield components. Further research is required to find out how plant density affects yield components. A nutrient omission trial could be implemented to see how soybean yields react to different nutrients and different timing of nutrient application. It is necessary to keep in mind that crop rotation is another important factor influencing soil fertility and in the long-run soybean yield. If soybean yield cannot be risen in an economically worthwhile way other cash crops such as sesame or cotton should be taken into consideration. It would be recommended to elaborate on insects, pests and diseases as it is also an important crop management option.

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