Cowpea-maize relay cropping

A method for sustainable agricultural intensification in northern Ghana?

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MSc thesis (minor)
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Executive summary

Northern Ghana has an annual human population growth of around 2% and includes some of the most food insecure regions of the country, and therefore, a clear need exists for sustainably increasing crop yields. Currently maize is the most important cereal and one of the most important staple crops of northern Ghana. By adding a short duration cowpea variety, in the form of a cowpea-maize relay cropping system, to this maize cropping system, overall yields could increase, soil fertility could be improved, and cropping systems could become more diversified. The early cowpea crop could also provide more nutritious food in a part of the season when not many other crops are mature yet and when stocks of the previous season have run-out. Cowpea-maize relay cropping could therefore be an option for sustainable agricultural intensification (SAI).

Through a cropping experiment and interviews, it was assessed how cowpea-relay cropping fitted within the farming system of northern Ghana and thereby could be an option for SAI. Experiments were carried out in two villages, Kpatarr Bogu in Karaga district and Bundunia in Kassena Nankana district, which were situated in two different agro-ecological zones (AEZs). The experiment was carried out on a fertility gradient, whereby in both villages a high, medium and low fertility field was selected. Different planting arrangements of cowpea-maize relay cropping were tested. One factor considered planting time of maize into the cowpea (3 or 6 weeks after planting the cowpea) and another factor within row planting arrangement (1 maize plant after 1 cowpea plant or 2 maize plants after 2 cowpea plants). Treatments were fully replicated and the same planting density was used for all treatments (53333 plants ha^{-1}, for both crops). Cowpea was harvested at mid-pod filling stage and maturity to assess grain yields, potential N-contributions and profitability. Only the cowpea crop in the cowpea-maize relay configuration was considered. Interviews in Kpatarr Bogu (30) and Bundunia (26) were used to construct a farm typology and to assess opportunities and constraints of cowpea-maize relay cropping tested in the experiments.

Results suggested that in both villages, two of the three fields did not clearly differ from each other in soil fertility. Planting arrangements did not significantly affect total biomass nor grain yields of cowpea in both locations. Although soil fertility, nodulation and expected climatological conditions were better in Kpatarr Bogu than in Bundunia, average yields were higher in Bundunia (0.91 Mg ha^{-1}) than in Kpatarr Bogu (0.68 Mg ha^{-1}). The lower yield in Kpatarr Bogu was probably caused by prolonged dry spells. Dry spells might also have overridden impacts from planting arrangements in Kpatarr Bogu. Low maize germination rates (21–33%) may be the reason behind the lack of effects from planting arrangements in Bundunia. Maximum biomass yield was not affected by fertility level in both locations, whereas grain yield was. Fields having a higher fertility also had more positive N-budgets and higher financial benefits. Nitrogen-budgets only showed positive contributions of N if all residues were left in the field (16–33 kg N ha^{-1}) or if N from stover was returned into the field the form of manure (11–22 kg N ha^{-1}). Taking all above ground plant parts out of the field or not considering below ground plant parts in the N-budgets would result in close to neutral (2–6 kg N ha^{-1}) or negative balances (-20 – -10 kg N ha^{-1}) respectively. The cowpea crop was profitable for all fertility levels, also if cowpea was considered a sole crop and all costs needed for cowpea cultivation were taken into account. Benefit-cost ratios ranged from 1.55 to 2.45 if cowpea was seen as an additional crop and only additional costs were taken into account. From the interviews it was found that farmers owned less land and depended more on off-farm income in Bundunia than in Kpatarr Bogu. Peak food shortage also lasted longer in Bundunia. For poorer farmers, cowpea could not 'fill' the whole food-gap in Bundunia and other measures like increasing total farm productivity would be needed. In both villages however, early cowpea matures more than one month earlier than other legumes and other crops. Currently cowpea is sown as one of the last crops, as farmers are afraid that maturing pods are affected by heavy rains during the season. 17% of the households in Kpatarr Bogu and 38% of the households in Bundunia cultivated short duration (erect) cowpea varieties in the previous season, which seemed to be mostly 'better-off' households. The need for insecticides and spraying alongside with the shortage of funds at the end of planting season, were said to be the most important constraints for short duration cowpea cultivation.

In this study, it was found that cowpea in a cowpea-maize relay configuration can produce more nutritious foods in a period of the year when there is food shortage. Maize was not considered in this study, therefore no conclusions can be made about whole season productivity. If best practices are used in residue management, the cowpea relay crop can contribute small amounts of N to the soil N-budget. Financial and N contributions were better for high fertility fields than for low fertility fields, resulting in less incentives to use this technology in poorer fields. The cowpea relay crop was however profitable for all fertility levels and resulted in considerably higher yields than current farmer reported cowpea yields. Cowpea-maize relay cropping (including improved crop management practices as tested in this study) therefore seems to be an option that fits within the paradigm of SAI. 'Poorer' farmers may however need special attention when promoting this technology since they currently do not grow this type of cowpea and find it harder to assess inputs like seeds, insecticide and fertilizers. Since cowpea-maize relay cropping was 'far' from current cropping practices, this might need special attention when considering dissemination in northern Ghana.

Introduction

Food security is at risk in sub-Saharan Africa (SSA) and will continue to be so if no changes are made in current trends of food production (SDSN 2013). From 1970 to 2000 population increased from 270 to 625 million in SSA and it is predicted to further increase to 1245 million in 2030. Which is an annual increase of 2.25%, the highest in the world in comparison with other regions (Alexandratos and Bruinsma 2012; DESA-UN 2009). In the past decades, yields per ha and per capita only marginally increased in SSA, especially in comparison with other world regions. Increase in production came mainly through expansion of cultivated land (Haggblade and Hazell 2010).

Nutrient availability is the most limiting factor in crop production in most areas of SSA (Breman et al. 2001; Van Keulen and Breman 1990). At the same time, research shows that nutrient stocks available in the soil are at risk, leading to degraded areas (Smaling et al. 1997). Increasing crop production through the use of external nutrient inputs might therefore be needed to sustainably attain household or regional food security in SSA, but is often not within the reach of smallholder farmers (Tittonell and Giller 2013; Vanlauwe et al. 2010).

Northern Ghana is a typical example of these described challenges. The three administrative regions of northern Ghana, the Upper East, Upper West and the Northern Region, together are often called the 'grain basket' of Ghana (Wiredu et al. 2010). Due to increased population pressure, Ghana, like many other areas in West Africa, has seen a change from shifting cultivation to continuous cropping (De Ridder et al., 2004; Nye and Stephens 1962 as cited in Adjei-Nsiah et al. 2004). Soil fertility regeneration through bush-fallow periods was therefore left out or reduced, making agricultural systems dependent on nutrient inputs from outside the cropping fields. Main sources of nutrients are manure from livestock that is ranging on common lands, mineral fertilizers or in the case of nitrogen, through biological nitrogen fixation (De Ridder et al. 2004; Giller 2001). Increasing population presure has lead and still leads to expansion of land under crop production in northern Ghana (Braimoh 2006).

Challenges of maize based cropping system

Like in many other areas of SSA, maize (*Zea mays* L.) is the most cultivated crop in northern Ghana (Wiredu et al. 2010). For the whole of Ghana, maize recently took over the lead from yam in terms of total area cultivated. Together with yam and cassava, maize is one of the most important staple crops of Ghana, and the most important cereal (MoFA 2011). Most common dishes of northern Ghana are based on maize. Popular for breakfast is 'coco', fermented maize porridge. The base of many hot meals is some sort of maize dough, either made out of ordinary or fermented cooked flower, 'TZ' and 'Banku' respectively. These are eaten with groundnut soup or green leaf soup for instance. The dominance of maize and other staples like cassava and yam in the north Ghanaian diet cause two important challenges. Staples on one hand contain much less proteins than animal products or pulses and also not all types of amino acids needed, are present in these staple foods (De Jager 2013). And on the other hand, soil fertility is affected. Continuous maize cultivation results in reduced yields, in particular if low amounts of nutrients are added to the system (Fosu et al. 2012).

Since maize is of such importance, cropping systems have to be developed that are based on maize, but also include other crops than can contribute to human nutrition and improve soil fertility. Addressing both these two challenges, the incorporation of legumes in the cropping system is often seen as an important option (Giller 2001). Legume grains and stover are nutritious food and feed in terms of protein content and quality. At the same time their ability to biologically fix nitrogen from the air enables legumes not only to depend on soil N or even contribute to the soil N stock (Giller and Cadisch 1995; Giller 2001). Intercropping and rotations of maize with legumes is often found to increase yields and economic benefits of the cropping system as a whole (Giller 2001). Therefore, legume-maize cropping systems can be an important system to increase agricultural production in northern Ghana and thereby improve food security in the region.

Cowpea-maize relay cropping is a potentially successful maize-legume cropping system for northern Ghana. Adding cowpea (*Vigna Unguiculata* (L.) Walp.) to the maize cropping system could improve total yields, food security, soil fertility and profitability of the maize cropping system which can therefore be seen as a form of sustainable agricultural intensification (SAI). The newly evolving paradigm of SAI was defined for the Sustainable Development Goals, aiming at increasing agricultural production sustainably to increase future food security (SDSN 2013).

This study took place in Karaga district, part of the Northern Region and in Kassena Nankana district, Upper East Region. Both districts show considerable population growth rates, 2.8% and 1.7% per year for the Northern Region and the Upper East Region respectively (UNDP 2010a; 2010b). Subsequently, this will lead to increased demand for food production and an even higher pressure on agricultural lands. Currently 11% of the population in Karaga and 33% of the population in Kassena Nankana district is food insecure during the lean season (studied at the end of the dry season/early part of the wet season). Kassena Nankana is therefore one of the most food insecure districts of the country (Hjelm and Dasori 2012). Cowpea, as an early crop in cowpea-maize relay cropping, could therefore not only increase total productivity, but also be an important source of food during this lean period.

In this study it was assessed how cowpea-relay cropping fitted within the farming system of northern Ghana by conducting cropping experiments and interviews. This study focused merely on the cowpea component of the relay system.

Theoretical framework

Sustainable agricultural intensification

Food security from the agricultural perspective depends on two parts, productivity of a current system and the sustainability of this productivity for the future (Garnett et al. 2013). Sustainable agricultural intensification is often proposed as a means to enhance food security in developing countries and Africa in particular (SDSN, 2013; The Montpellier Panel, 2013). Some authors call it slightly different, for example eco-efficient agriculture (Keating et al. 2010), sustainable intensification (Garnett et al. 2013; Pretty et al. 2011; Smith 2013) or ecological intensification (Cassman 1999). The overall objective of those newly evolving paradigms are however similar. Built on this work, the Sustainable Development Solutions Network (SDSN) of the United Nations (UN) defined the objective of SAI as follows:

> 'To provide sufficient, accessible, nutritious food, while enabling economic and social development in rural areas and treating people, animals and the environment with respect.' (SDSN 2013, p. 16)

The definition of SAI therefore became:

> 'To deliver more product (food and other agricultural goods) per unit of resource, whilst preventing damage to natural resources and ecosystem services that underpin human health and wellbeing both now and in the future. ' (SDSN 2013, p. 16)

First and most important in SAI is to produce more food, but with less input per unit of output. Outputs can be increased in three ways; 1) through higher production, 2) through higher income or 3) by having more nutritious outputs (The Montpellier Panel, 2013).

At the same time the production per unit of land should be intensified in order to reduce the need for expansion of agricultural lands at the cost of natural areas like forests and wetlands (Pretty et al., 2011; Garnett et al., 2013; SDSN, 2013; Smith, 2013; The Montpellier Panel, 2013). In some areas in SSA no natural land suitable for cultivation is available anymore, which is another reason to intensify the production on the land available (Garnett et al. 2013). While in the past, increase in agricultural production in SSA mainly depended on the expansion of farm land (Haggblade and Hazell 2010). Expansion of farm land is also often a way to circumvent reducing nutrient stocks and the subsequent shortage of nutrients for crop growth (De Ridder et al. 2004), which might eventually not be sustainable.

Soil fertility is a major constraint to build more productive and resilient cropping systems in SSA (Breman et al. 2001; De Ridder et al. 2004; Keating et al. 2010). In many areas, current crop production depends on nutrient mining (Smaling et al. 1997). When this process is continued, with no sufficient replenishing of nutrient stocks and low current stocks, this results in negative impacts on soil fertility which can eventually lead to degraded soils (De Ridder et al. 2004; Vanlauwe and Giller 2006). In these systems with virtually no external inputs, adding small quantities of nutrients would positively increase nutrient use efficiency, productivity, soil fertility and thus sustainability of the cropping system (Keating et al. 2010). Important in this context is also that, where possible, organic and mineral fertilizers should be combined to increase nutrient use efficiency and improve soil quality (Giller et al., 1997; Vanlauwe et al., 2010; The Montpellier Panel, 2013).

Cropping systems designed within the SAI paradigm should also be resilient, meaning that they should be more tolerant to stress (The Montpellier Panel, 2013). This can result in diversification of cropping systems, development of dry spells resistant varieties or for example the afore mentioned maintenance of healthy soils (Keating et al. 2010; Pretty et al. 2011). Building these resilient systems contributes to future food supply and thereby, food security can be increased in changing environments.

All these 'solutions' and components of SAI should be 'context-specific strategies'. They should not only fit into a certain bio-physical environment but, in order to be successful, also be adapted to socio-economic conditions present in an area (Ojiem et al. 2006; SDSN 2013). To ensure that such conditions are considered, systematic research is needed that incorporates the 'solution' as a component of the whole farming system and analyses whether it applies to the objectives of SAI (Giller et al. 2011; Keating et al. 2010). This type of research does not necessarily or directly lead to a 'perfect solution'. It should be a process of 'trial and error' in which techniques tested or implemented are reconsidered and improved in the process of implementation (SDSN 2013). Conducting farmers evaluations, resulting in the use of farmer criteria for the evaluation and selection of new technologies, can be such a method (Adjei-Nsiah et al. 2008). Only when 'solutions' are implemented, evaluated and improved in multiple cycles, such 'solutions' can contribute to sustainable intensification of SSA agricultural systems (Giller et al. 2008; SDSN 2013).

N_2-fixation

The most limiting factor for plant growth in SSA is nutrients, of which N is the most limiting one. In SSA mineral fertilizers are often hard to access for smallholder farmers due to: distance from retailers, high prices or other financial constraints and risks related to these financial constraints. Legumes can be a 'free' source of N (Giller and Cadisch 1995; Giller 2001; Peoples et al. 1995). 'Free' can however be a relative term in this as legume technologies come for example often with extra labour demands or specific input needs (Vanlauwe and Giller 2006). How such a new technology fits within an existing smallholder farming system, including environmental and socio-economic opportunities and constraints, is one of the main questions that should be answered when trying to assess the possible success of such a new technology (Giller et al. 2011; Ojiem et al. 2006).

First the basic principles of N_2-fixation are discussed. Most of the *Leguminosae* are able to form a symbiosis with bacteria of the rhizobia group. They form nodules through which the rhizobia fix and provide N from the air (N_2) to the plant in return for sugars, which are provided by the plant to the rhizobia. Cowpea and soya bean (*Glycine max.* (L.) Merr.), two important legumes in SSA, form for example a symbiosis with the slow growing *Bradyrhizobium* genus while common bean (*Phaseolus vulgaris*) forms a symbiosis with the *Rhizobium* genus. Legume species and varieties can either be promiscuous or non-promiscuous in their ability to form a symbiosis with different rhizobia-strains (Giller 2001). Soya bean is for example generally non-promiscuous and therefore only forms symbiosis with a few *Bradyrhizobium*-strains, although there are soya bean varieties that are more promiscuous. Cowpea is a promiscuous species, which is therefore able to form a symbiosis with many *Bradyrhizobium*-strains present in SSA soils (Giller 2001).

Leguminosae thus have two sources of N, from the soil and from the air, resulting in less depleted or increased soil N-stocks if legumes are grown. How much N_2 is fixed from the air, how much this is in proportion to the total amount of plant-N and whether a plant is a net contributor of N to the soil, depends on: the plant species, the rhizobia present in the soil, the environment in which the plant grows and how it is managed (Giller and Cadisch 1995).

Different methods can be used to assess N_2-fixation. Observing the growth of a plant and colour of the leaves, taxonomy, nodulation and plant N-accumulation in poor soils, can be good indicators for N fixation. 'Measuring' the percentage of N accumulated through N_2-fixation is most commonly done through N-difference methods. The natural abundance technique for instance works from the principle that the proportion of ^{14}N and ^{15}N is always the same in the air and usually different from that of the soil N pool. Plant species that also obtain N from the air have thus a different $^{14/15}N$ signature than those that do not (Giller 2001; Unkovich et al. 2008). N-difference methods all have a range of potential errors and should therefore only be used as an estimate N_2-fixation (Giller 2001).

The actual contribution of N from a legume crop to the soil depends on the total amount of N accumulated through N_2-fixation and the amount of N exported from the field (Peoples et al. 1995). The largest part of N that is exported, is exported through the grains, but often whole pods are harvested, therefore also husks are exported. Legume stover is protein rich and therefore good feed for livestock. This means that also sometime also stover is taken out of the field and only roots remain. Part of the N fed as fodder to the livestock may be returned to the field as manure. Management does therefore not only influence how much N is fixed, but also how much N eventually is added or subtracted from the soil N-stock.

N2Africa – research-in-development

This study is part of the N2Africa project which has as subtitle: 'Putting nitrogen fixation to work for smallholder farmers in Africa'. N2Africa uses legumes to improve cropping systems in SSA by using a 'research-in-development' strategy. It is led by Wageningen University in collaboration with the

International Institute of Tropical Agriculture (IITA) and many other local partners (www.N2Africa.org). The project first started in 2009 sponsored by The Bill & Melinda Gates Foundation and a later extension in 2012 was sponsored by The Howard G. Buffet Foundation that also enabled the project to work in Sierra Leone, Liberia and the Kivu provinces in DR Congo. In November 2013 the The Bill & Melinda Gates Foundation extended the project for a phase II with a US$ 25.3 million grant for 5 more years to reach an additional 550.000 smallholders. The core countries of phase II are Ghana, Nigeria, Ethiopia, Tanzania and Uganda, while work is also continued in DR Congo, Rwanda, Kenya, Mozambique, Malawi and Kenya (N2Africa 2013).

'Research-in-development' for smallholder farmers in SSA is needed to understand the opportunities and constraints for legume-based technologies for smallholder farmers (Giller et al. 2011; SDSN 2013). In phase I mostly 'best-bet' have been used. For example, based on knowledge from local experts, best legume varieties for each country were selected (Baijukya et al. 2010). These were then used in dissemination trails on farmers' fields. The purpose of these trials was to show the benefits of improved legume varieties, P-based fertilizer and rhizobia-inoculants (rhizobia-inoculants only if common bean or soya bean were tested). These trials are used to analyse the success of these 'best-bet' technologies to improve them further and in future to come to 'best-fit' technologies (Giller et al. 2011; N2Africa 2013).

'Best-fit' technologies are needed to sustainably intensify smallholder farming in SSA (Giller et al. 2011; SDSN 2013). Farming systems are highly heterogeneous on all levels. Tittonell et al. (2005a) and Tittonell et al. (2005b) described how variation on regional, village and farm level determined the performance of maize and how this differs per farm type. Farm types were determined based on amongst other things, resource endowment, total land area owned and cultivated and the age of the household-head. Kamanga et al. (2010) showed how similar variables influence the riskiness for smallholder farmers to take up new legume technologies. The previous section also described how environment and management influence the productivity of legumes. This results in a wide range of variables where technologies or 'solutions' should apply to (Ojiem et al. 2006), to become 'best-fit' technologies. The cycle of development, similar to that as described for SAI 'solutions', is used within N2Africa to consider all these variables for the continuous development and re-development of legume technologies. In phase II of N2 Africa, improved technologies of phase I are used and tested within the project itself, but also through PhD and MSc research like this one (N2Africa 2013).

Cowpea-maize relay cropping

Besides common bean, groundnut and soya bean, cowpea is a focus crop within the N2Africa project. As an indigenous legume of West-Africa, it is well adapted to the sometimes harsh conditions like dry spells and heat (Ehlers and Hall 1997). At the same time it is also one of the legumes that has a potential to substantially contribute to the soil N-budget (Giller and Cadisch 1995). This combined with its high nutritious value and market demand in northern Ghana (Langyintuo et al. 2003), makes that cowpea might fit well within the context of smallholder farming in northern Ghana.

Franke et al. (2004) proposed to use relay-intercropping of cowpea and maize as option to fit two crops within one mono-modal rainfall season as present in Northern Ghana. In this system a short duration variety of cowpea is planted first and about half way its growth a short duration maize crop is sown within the cowpea crop. Using relay intercropping results in a reduction of water stress at the end of the season for the maize compared to cases where both crops would be grown in mono-crop after each other. By having two crops in relay, instead of only maize, the land can be used more efficient over the whole season, resulting in a more intensified system. In this cropping system, produce of cowpea would become available early in the cropping season. This will lead to an increased food security during a part of the season when stocks are running out and new crops are still in the field, the lean period (Blahut and Singh, 1999 as cited in Carsky et al., 2001; Ehlers and Hall, 1997). Meanwhile maize, an important staple crop, is growing in the same field. The short duration cowpea crops also result in quick (financial) returns, often a prerequisite for the success of the introduction of legumes in a cropping system (Schlecht et al. 2006).

This study uses the main objectives of SAI and N2Africa to come to an improved cropping technique. It aims at finding the best planting arrangement in time, by having two different planting times for the maize and in space, by having two different ways of spacing the maize and cowpea. The effects of environment are tested in the form of a soil fertility gradient (high, medium and low fertility fields) and as influenced by agro-ecological zone (AEZ). To assess current cowpea cultivation and farmers regarded advantages and disadvantages of cowpea-maize relay cropping, this is supplemented with a questionnaire in the two communities where the experiments were held. Combined, these methods aimed at assessing how the tested cowpea-maize relay cropping arrangements would fit for different types of households in different environments and how this would comply with the principles of SAI.

Problem statement

Theoretically cowpea-maize relay cropping can be a cropping system that fits well within the concepts of SAI and be an option to smallholder farmers in northern Ghana. How this works out in practice, whether it is already used and how it is considered by smallholder farmers in northern Ghana, is however unknown. In the previous sections it is explained how field fertility, AEZ, planting arrangements, N contributions, economic returns and for example farmers perceptions could influence the success of a technique. There is therefore a need to test cowpea-maize relay cropping and assess its performance for these factors in northern Ghana.

Objectives

The main objective of this research is to assess the potential of short duration cowpea grown in relay before the consecutive maize crop for sustainable agricultural intensification, in two different AEZs of northern Ghana.

This can be divided into the following sub-objectives:

1) To describe the current cropping system and characterize cowpea cultivation.
2) To assess the effect of AEZ and soil fertility on yield and total biomass of the short duration cowpea crop.
3) To compare the effect of different planting time and spatial arrangements of the cowpea-maize relay cropping system on yield and total biomass of the short duration cowpea crop.
4) To assess the interactions between AEZ, soil fertility, and planting time and spatial arrangements of the cowpea-maize relay system on the cowpea crop in terms of grain yield and total biomass.
5) To quantify contributions of the short duration cowpea crop to the field N-budget.
6) To estimate the economic contribution of the cowpea relay crop as added to the maize cropping system.
7) To explore whether the early cowpea could act as a food source during the lean season.
8) To describe what happens to cowpea residues and thereby their role in contributing to soil fertility.

Objectives 2 to 5 were assessed in field experiments. To supplement the results of these experiments and to characterize the context in which this cropping system should fit, interviews were held to assess objectives 1, 7 and 8.

Methodology

This study consisted of two parts; cropping experiments that were conducted in three different fields in two villages, and interviews that were held in the same two villages.

The cropping experiment was part of the experiments setup for the PhD research of Michael Kermah (Wageningen University, Plant Production Systems) which had the objective to determine the differences in benefits of cowpea-maize relay systems in comparison with rotations of soya bean with maize, groundnut with maize, maize after maize and fallow-maize. The total experiment would be conducted in two consecutive years. The results as presented in this research are on the first year (2013) and only on four (of the in total ten) planting arrangements present in each field.

Locations

The two villages were both located in districts of northern Ghana that are part of the N2Africa action sites, namely Karaga district and Kassena Nankana district. Kpatarr Bogu village is located in Karaga district (N 9° 58' 20", W 0° 39' 58"), while Bundunia village is part of Vunania operational area which is situated in Kassena Nankana district (N 10° 51' 26", W 1° 4' 44").

The experimental fields in Kpatarr Bogu were located on dystric plinthosols which originated from shales (UNDP 2010a), in Bundunia they were on gleyic lixisols which originated from granite (UNDP 2010b).

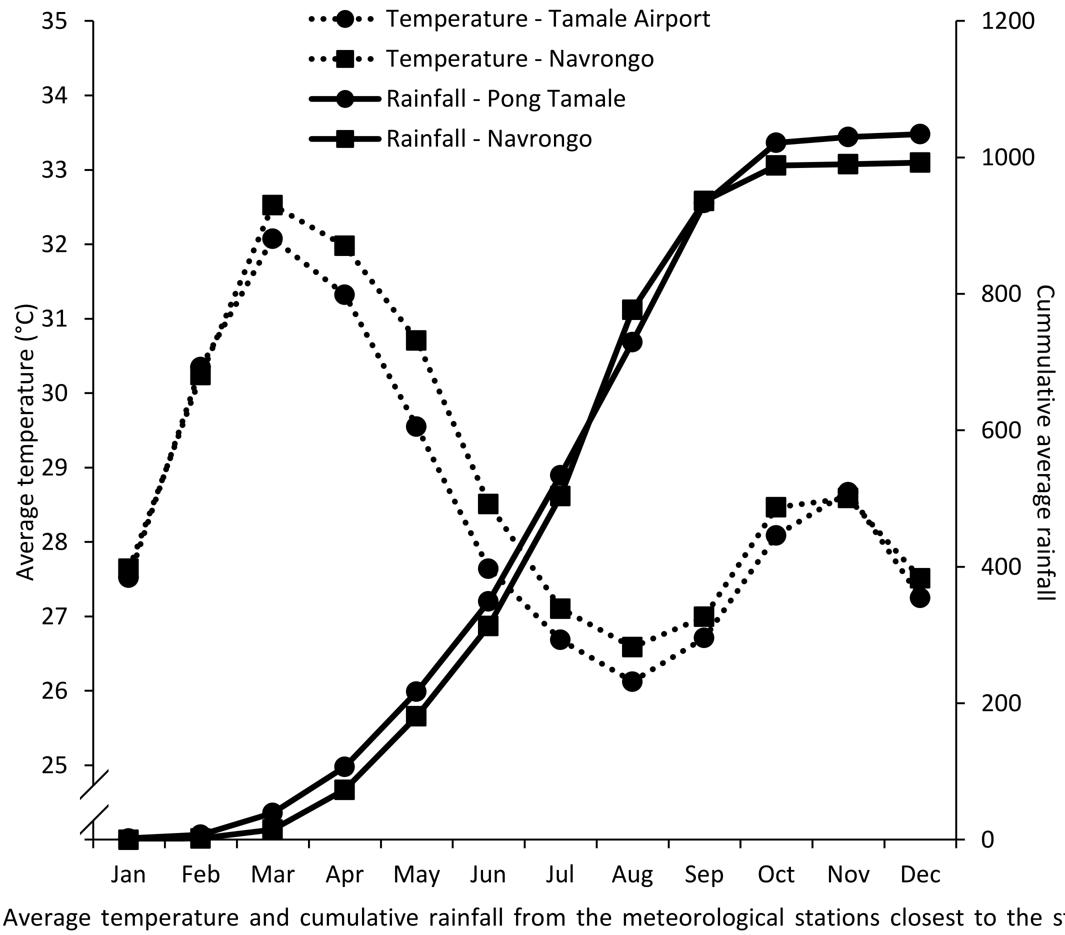

Fig. 1. Average temperature and cumulative rainfall from the meteorological stations closest to the study sites, Navrongo (2.5 km) in Kassena Nankana for both parameters, Pong Tamale (33 km) for rainfall and Tamale Airport (50 km) for temperature in Karaga district. All average were based on data from 1970-2013, Ghana Meteorological Services, Legon, Accra.

Climate

Kpatarr Bogu is situated in the Guinea Savannah agro ecological zone (AEZ) while Bundunia is still in the Guinea Savannah AEZ, but on the border with the Sudan Savannah AEZ (Dickson and Benneh, 1988 as cited in Oppong-Anane, 2006). The Guinea Savannah has a growing period of 180-200 days while in the Sudan Savannah the growing period is 150-160 days. Both AEZs have a unimodal rainfall pattern (Oppong-Anane 2006).

Meteorological data was obtained from the Ghana Meteorological Services in Legon, Accra, for stations that were situated closest to the study areas. From the 32 year averages it can be concluded that Bundunia (Navrongo) has a higher average temperature than Tamale Airport, which is closest to Kpatarr Bogu, 50 km from the site (Fig. 1). This difference is however only 1.1 °C in June at the start of the cropping season and becoming less further on. The difference is mostly determined by a higher maximum temperature, 33.3 °C in Navrongo in June, while 31.8 °C in Tamale Airport.

Total average rainfall per year for Pong Tamale is 1034 mm and 992 mm in Navrongo. Rains start about two weeks later in Bundunia and have a higher peak. In August there is on average 273 mm precipitation in Navrongo against 195 mm in Pong Tamale.

Fertility gradient

The aim was to obtain fields that were low, medium and high in soil fertility for the experiments. This objective was first discussed with the Agricultural Extension Agents (AEA) of the Ministry of Food and Agriculture (MOFA) of Ghana, who were responsible for the two areas. According to their experience and knowledge of the area, different farmers and fields were visited. First the trials were explained to farmers and their readiness to cooperate was assured of. If the fields suited the requirements for the trial (no trees in the plot or too close to the field or other unavoidable discontinuities, suitable size), an interview was done to obtain information on the field history. Besides the information as shown in Table 5, the interview revealed information on within field variability like boulders, water logging or fertility gradients. Specific spots like a rock or a termite mound were avoided. Stony patches as found in the high and low fertility fields of Bundunia were captured within a block. Also the fertility gradient from the higher to the lower part in the low fertility field in Bundunia was captured by putting the blocks perpendicular to the fertility gradient.

The information obtained through the questionnaires, together with the AEA's and farmer knowledge and the observations in the field determined whether the field was used for the trials. From each field also soil samples were taken (0-15 cm, 10-15 samples per site taken in a w-shape which were put together to make up a composite sample). Samples were analysed for pH (1:1 H2O), Organic Carbon (Walkley & Black), total N (Kjeldahl), available P (Bray I), total K, Ca and Mg (Ammonium Acetate) and particle size by the soil laboratory of the Savanna Agricultural Research Institute (SARI). Afterwards, these results were examined to see whether the assumed fertility gradient could be shown by the different parameters tested.

Planting arrangements

Temporal and spacing arrangements were tested in each environment (fertility levels, AEZs). Spacing was altered by changing within row arrangements, having one cowpea plant after one maize plant (1×1) or two cowpea plants after two maize plants (2×2). With the 1×1 planting arrangement, spacing between the maize plants was 25 cm and between these future maize stands, one cowpea plant was sown (Fig. 3). With the 2×2 planting arrangement, spacing between the maize planting stations was 50 cm, while there were two plants sown per planting station (Fig. 4). Between these future maize planting stations two equally spaced cowpea plants were sown. Between row spacing for all treatments was 75 cm. All spacing arrangements therefore had the same planting density of 53333 plants ha^{-1} for each crop. For maize this was a recommended density, while for cowpea it is about 1/2 or 1/3 of what is recommended. This was done to prevent too much competition of the cowpea on the maize when the maize emerges. As maize is a staple crop it is often regarded as more important by farmers.

Maize was relayed into cowpea at three (3wk) or six (6wk) weeks after planting cowpea. It was tried to plant closest to this dates, but also at a moment when sowing was feasible, after rains (causing moist soil). All levels of planting time of maize and spacing arrangement were combined, resulting in four planting arrangements in each fertility level; 3wk2×2, 6wk2×2, 3wk1×1 and 6wk1×1 (Table 1).

Table 1 Summary of planting arrangements in the early cowpea-maize relay trial, whereby cv. Dorke SR in Kpatarr Bogu and cv. Dodzi in Bundunia were used as relay maize in the cowpea crop (cv. Songotra).

Planting arrangement	Crop (variety)	Time of sowing (weeks after start of season)	Spacing	Plant density (plants ha^{-1})
3wk1×1	Cowpea (Songotra)	-	2 seeds equally spaced within row between maize planning stations	53333
	Maize (Dorke SR or Dodzi)	3	50 cm between planting stations, two seeds per planting station	53333
6wk1×1	Cowpea (Songotra)	-	2 seeds equally spaced within row between maize planning stations	53333
	Maize (Dorke SR or Dodzi)	6	50 cm between planting stations, two seeds per planting station	53333
3wk2×2	Cowpea (Songotra)	-	1 seed between maize planning stations, within row	53333
	Maize (Dorke SR or Dodzi)	3	25 cm between planting stations, 1 seed per planting station	53333
6wk2×2	Cowpea (Songotra)	-	1 seed between maize planning stations, within row	53333
	Maize (Dorke SR or Dodzi)	6	25 cm between planting stations, 1 seed per planting station	53333

The first sowing of cowpea in both Kpatarr Bogu and Bundunia was done when rains were well established and fields had been prepared after the first rains. Specific dates can be found in Table 3. Rains started about one month later than expected. Therefore it was not feasible anymore to also use cv. Dorke SR (90-95 days) in Bundunia. Another shorter duration variety was chosen for Kpatarr Bogu, namely Dodzi (80-85 days,).

All varieties chosen were recommended varieties for Northern Ghana and either obtained through the seed inspection unit of MOFA or through SARI. They were mainly selected on their duration, to fit in a relay cropping system. To increase the viability of uptake, only varieties that are available in Northern Ghana were chosen. Before sowing, all seeds were manually inspected and unviable seeds were removed.

Table 2. Varieties used in the trial, whereby Dorke SR in Kpatarr Bogu and Dodzi in Bundunia were used as relay maize in the cowpea crop(Songotra).

	Year of introduction	Introduced by	Origin	Parental source	Maturity period	Type of variety
Maize[1]						
Dodzi	1997	CRI[2]	IITA	TZEE SR W	80-85	Short duration
Dorke SR	1992	CRI	IITA/CIMMYT	Pool 16-SR	90-95	Medium duration
Cowpea						
Songotra	2008	SARI	IITA	IT97K-499-35	60	Short duration

[1]Sources on varieties; maize (Ragasa et al. 2013; Sallah et al. 2008; Sallah et al. 1997), cowpea (Monyo and Boukar 2012).

[2]CRI, Crop Research Institute; IITA, International Institute of Tropical Agriculture; CIMMYT, International Maize and Wheat Improvement Center; SARI, Savanna Agricultural Research Institute

Outlay of experiments

The early cowpea-maize relay planting arrangements were part of a bigger experiment, including: maize with relay cowpea late in the season, single groundnut, single soya bean, single maize, and a fallow plot (Annex III). An example of the trial layouts can be found in Fig. 2. Plots were organized in a Randomized Complete Block Design (RCBD). Each fertility level contained four replicates of all ten crop and planting arrangements. Complete outlays (including irregularities) can be found in Annex II.

Each plot was 3.75 by 4.00 m, in total 15 m^2 and contained 5 rows. Harvested net plots were 2.25 by 1.00 m (2.25 m^2) for mid-pod filling harvest and 2.25 by 2.00 m (4.50 m^2) for final harvest sample. The plot for mid-pod filling harvest contained 12 cowpea planting stations and the final harvest plot 24 (Fig. 4).

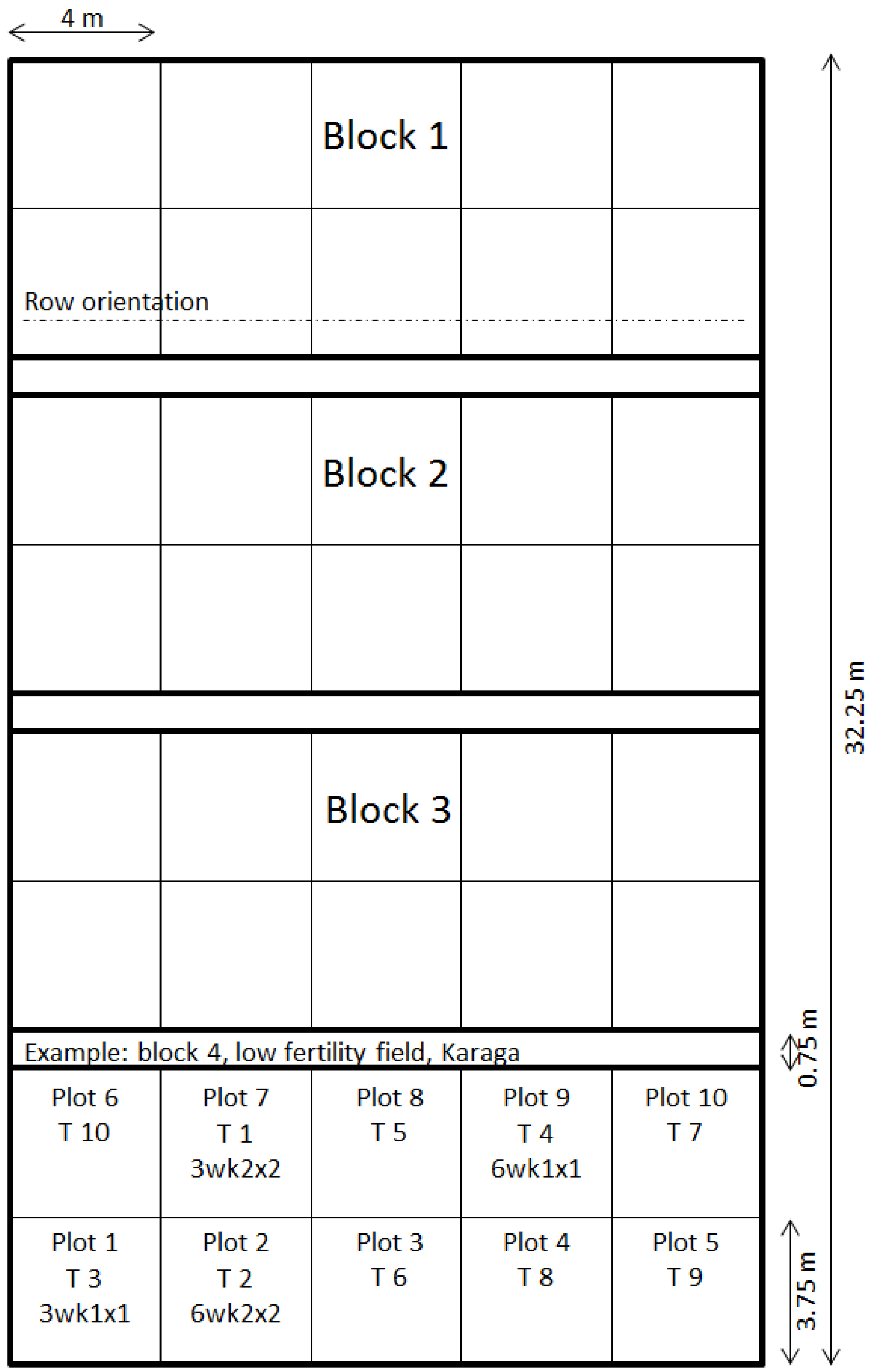

Fig. 2. Trial outlay as part of the complete relay-rotation trial. Block 4 shows how the four planting arrangements were part of a bigger experiment, using a randomized complete block design. Outlays of all fields and a summary of all planting arrangements can be found in Annex I.

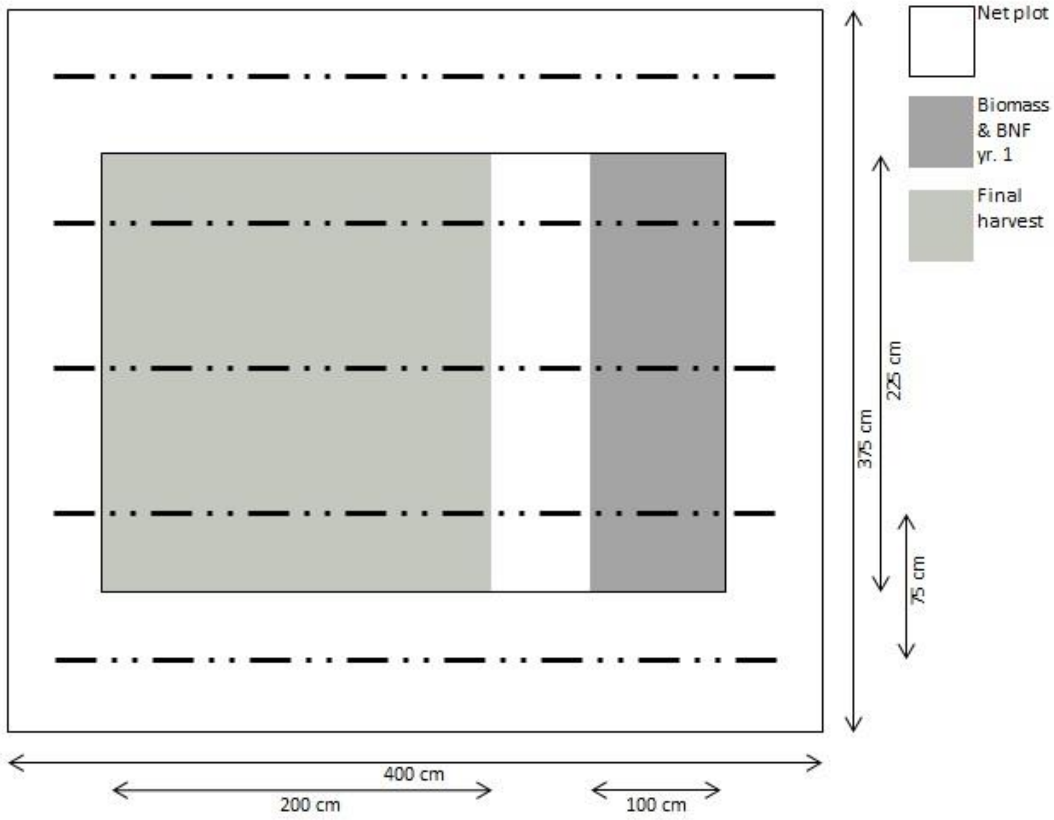

Fig. 3. Layout of the plots for planting arrangements 3wk2×2 and 6wk2×2 (not on scale). A dash stands for two maize plants in one planting station, a dot represents a cowpea plant. For the mid-pod filling harvest (biomass & BNF), an area of 2.25 m^2 was harvested, containing 12 cowpea plants. The final harvest is conducted on an area of 4.50 m^2 containing 24 maize and 24 cowpea plants.

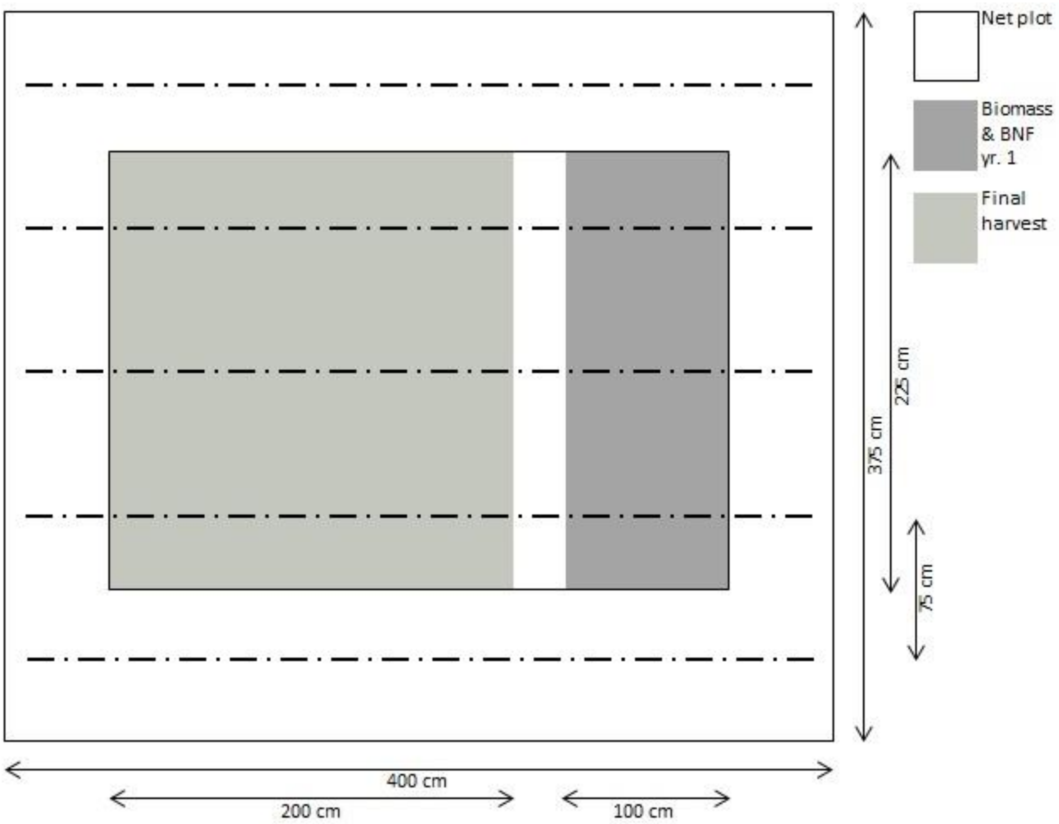

Fig. 4. Layout of the plots for planting arrangements 3wk1×1 and 6wk1×1 (not on scale). A dash stands for a maize plant, a dot represents a cowpea plant. For the mid-pod filling harvest (biomass & BNF) an area of 2.25 m^2 was harvested, containing 12 cowpea plants. The final harvest is conducted on an area of 4.50 m^2 containing 24 maize and 24 cowpea plants.

Management

Fields were prepared according to best local practices as used in Bundunia. In both places fields were first disc-ploughed with a tractor and then ridges were made. In Bundunia ridges were first made with a tractor and then manually adjusted for correct spacing between the rows. In Kpatarr Bogu ridges were made manually with hand-hoe's as ridges were not common here and thus no implements available.

P and K fertilizer was applied at sowing of the cowpea at a rate of 25 kg P ha^{-1} and 30 kg K ha^{-1}. P in the form of Triple Super Phosphate (TSP) and K as Muriate of Potash (MOP). Sowing was done along a line containing knots which determined planting distances. At a cowpea stand two holes were 'dibbled', one for the seed and one for the P and K fertilizer, at a future maize stand one hole was 'dibbled' for P and K fertilizer only. N in the form of urea was applied at a rate of 50 kg ha^{-1} to the maize plants, split in two doses at three and six weeks after planting the maize. Urea was applied in a hole, which was 'dibbled' close to the maize plant and closed after application to increase uptake efficiency. Plant gaps were refilled at two to three weeks after sowing if plants had not emerged. Plots were weeded manually using hand-hoe's at three and six weeks after planting cowpea and just before sowing the relay maize.

Cowpea was treated twice with insecticide (Wynco Cypadem 43.6 EC), containing 36 g of cypermethrin and 400 g of dimethoate per litre at a rate of 0.75-1.00 l ha^{-1}. Insecticide was only applied when pests were observed, at flowering and podding stages. In Kpatarr Bogu cowpea was also sprayed twice with lambda-cyhalothrin before, to control leaf eating insects.

Table 3. Cowpea management dates in Kpatarr Bogu and Bundunia (dates and days after planting (DAP)).

Activity	Kpatarr Bogu		Bundunia	
	Date	DAP	Date	DAP
Land preparation	June 15-29	-	July 9-17	-
Planting cowpea	June 30	-	July 16-17	-
1st insecticide application	August 11	42	August 20	35
2nd insecticide application	September 2	64	September 6	52
1st weeding	June 18-20	18-20	August 5-9	20-21
Sowing relay maize 3wk	July 23	23	August 7	22
2nd weeding	August 12-13	43-44	August 24-26	39-41
Sowing relay maize 6wk	August 16	47	August 29	44
Biomass harvest	August 22-28	53-59	September 12-19	58-65[1]
Pod harvests	Aug. 31-Sept. 8	62-70	September 28	74[1]
Final harvest	Sept. 15-21	77-83	October 2-3	78-79[1]
Spraying lambda-cyhalothrin 1	July 13	13		
Spraying lambda-cyhalothrin 2	August 2	33		
Re-ridging	August 23-24	54-55		

[1] Block 1 and plot 184 in the medium fertility field were almost completely eaten by stray animals after emergence and therefore re-filled at two weeks after planting. Mid-pod filling, pod and final harvest of these plots were subsequently also about two weeks later than other plots.

Observations and measurements

All dates of management activities, observations and measurements were recorded, most important events can be found in Table 3. At both sites rainfall was recorded in two places using rain gauges; one was read by a farmer close to the experimental fields and the second one by the AEA. In Kpatarr Bogu the AEA stayed in Karaga town, 27 km from the actual fields. As in both places the observations by the farmers seemed reliable and were taken closer to the experimental fields, these was used in the results section.

Two to three weeks after planting, emergence rate was recorded by counting all emerged plants in the first two meter of each row. Physiological dates for 50% flowering, mid-pod filling stage and maturity were recorded. Mid-pod filling stage was defined as the moment when 50% of the pods reached their full size, while the other part is still developing to become so. If observed, pests and diseases were noted and given a score (1-3, were 1 was almost no visible damage and 3 was severe damage, seriously affecting yield).

Mid-pod filling harvest

At mid-pod filling stage of the cowpea, the subplot for mid-pod filling harvest, as indicated in Fig. 3 and Fig. 4, was harvested and actual number of plants was recorded. Plants were separated into shoots and pods and fresh weight of both was determined using an electronic kitchen scale. From both representative subsamples of 300-500 g were taken and actual weight recorded. These subsamples were as soon as possible taken to the SARI laboratory and dried for at least 48 hours (stover) or 72 hours (pods) at 75 °C, after which dry weight was determined.

At mid-pod filling harvest, also nodulation was assessed. In each plot 10 plants were carefully uprooted and cleaned from soil particles. The number of nodules was counted and if present, a 'C' for crown nodulation was noted. For each plant two nodules were cut open. If a nodule was red/pink/brownish an 'R' was noted, which later translated into '1' for an active nodule, if grey or green a 'G' was noted which translated into a '0' for a not active nodule. Averages per plot, for both number of nodules and active nodules were calculated and used for further analyses.

Final harvest

At maturity samples were taken from the final harvest area as indicated in Fig. 3 and Fig. 4. Before final harvest of the whole plants, mature pods were harvested once or twice, also here total fresh weight was recorded and representative subsamples were taken. Separate subsamples of pods were later combined for each plot. At final harvest, actual number of plants was recorded. Plants were separated in pods and stover. Shed biomass found on the ground in the harvested area was taken and counted as stover. Fresh weight of all representative subsamples (300-500 g) was recorded after which samples were dried at 75 °C for 48 hours (stover) or 72 hours (pods) to determine dry weight. From the pods, grains were removed and dry weight of empty pods and grains was recorded.

Data analysis

All results were entered into Microsoft Office Excel spread sheets for further analyses. Harvest data were calculated from a harvested plot base to yield ha^{-1}. Outliers and other unexpected outcomes were analysed. Variation between plots was found for places where irregularities were observed in plots like ploughing trenches or plot specific low germination rates, but also for plots where no specific irregularities were found (Annex II). Since no clear distinction between those two kinds of variation could be made, no outliers or irregularities were deleted.

Results were subjected to Analyses of Variance (ANOVA) to determine differences between means in a split-plot analysis with fertility level as main plot and planting arrangements as sub-plot. Differences were considered significant if $P<0.05$. Fisher's protected LSD was used to determine whether means significantly differed from each other. All results were tested for normality, using Shapiro-Wilk test and for homogeneity, using Barlett's test for homogeneity. Barletts's test for homogeneity assumes normality and could thus only be performed if normality was not significant. If one of those tests gave a significant outcome, this is noted in the results section and results were interpreted with care. Statistical analysis was carried out using GenStat, 15th edition, VSN International Ltd 2012.

Calculations

Based on yield data, price information and literature review, partial field N-budgets and a cost-benefit analysis were constructed. Partial N-budgets were based on four scenario's, similar to the ones Laberge et al. (2009) used. Budget 1 only took into account N from above ground biomass measured (not the below ground biomass) and assumes that all residues and grains were harvested and completely removed from the field. Unkovich et al. (2008) state however that 30% can be a good estimate for the percentage of plant N that is contained in the below ground plant parts for grain legumes like cowpea. This assumtion is used for budgets 2 to 4, whereby total above ground N is devided by 0.7 to calculate whole plant N. Budget 2 also assumed that all residues and grains were removed from the field. This can be the case when residues are havested and used as fodder. Budget 3 assumed that only grains were removed from the field, with residues left in the field and not used as fodder. N from residues would then be entirely available for take up by the soil N pool. Franke et al. (2008) however found that vaste amounts of residues are lost over the dry season in northern Nigeria and do not actually contribute to soil N. Another option could also be that residues are taken from the field, fed to lifestock and then returned to the field in the form of manure in the next season. This is represented by budget 4, which assumes that this transfer of N in cowpea residues through livestock has an efficiency of 50%. A number that is also used by Laberge et al. (2009) and based on work by Franke et al. (2008) on crop-livestock systems in the northern Guinea Savannah of Nigeria. Franke et al. (2008) used stall-feeding of legume residues and bag storage of manure as an example of improved residue management, targeting at higher nutrient-use efficiencies.

N-budget 1 = ((% N fixed through N_2-fixation × above ground plant N)/100) - ($N_{residues}$ + N_{grains})
N-budget 2 = ((% N fixed through N_2-fixation × whole plant N)/100) - ($N_{residues}$ + N_{grains})
N-budget 3 = ((% N fixed through N_2-fixation × whole plant N)/100) - N_{grains}
N-budget 4 = ((% N fixed through N_2-fixation × whole plant N)/100) - ($N_{residues}$ + N_{grains}) + ($N_{residues}$ × 0.5_{manure})

%N fixed through N_2-fixation and N-concentration of stover and pods was based on values from literature. No different values for N concentration at mid-pod filling stage and at final harvest could be found. Therefore it was assumed that N-concentration of the different plant parts was the same at mid-pod filling stage and at final harvest.

Maximum total aboveground biomass for legumes is generally assumed to be at mid-pod filling stage. It was however found that a large proportion of the plots had a higher total biomass at maturity. Therefore, for each plot it was first determined when highest total biomass was recorded, either at mid-pod filling stage or at maturity. For the harvest with highest total biomass, the N concentration of stover and pods was multiplied with the amount of biomass harvest of both plant parts and subsequently summed up to obtain the above ground plant N.

To obtain values for whole plant N, above ground plant N was divided by 0.7. $N_{residues}$ and N_{grains} were based on weight at final harvest of residues, grains and remains of the pods and multiplied by the N concentration of each plant part as explained before. N concentration of the empty pods was assumed to be the same as that of stover and taken together with grains as always whole pods are harvested and shelled at the house. N-content of empty pods was therefore always assumed to be exported from the field. Only in budget 4 it was added to the residues that were fed to livestock and of which 50% of the N was returned to the field in the form of manure.

A simple cost-benefit analysis was carried out for two scenarios. Scenario 1 only took into account the additional cost needed to add cowpea as a relay crop to maize. This meant for example that as ploughing had to be done for the maize in any case, these cost were not included for the partial budget of cowpea in Scenario 1. It was estimated that one time extra weeding would be needed for the cowpea crop, representing an additional cost and included in Scenario 1. Other specific costs that were made for cowpea were: sowing, insecticide application (2x), harvesting and shelling. Scenario 2 took into account all costs that were needed for cowpea cultivation, adding to the cost of Scenario 1: ploughing, making the ridges and weeding (2x in total for cowpea). Cost for fertilizer, seed and insecticide were kept the same for both scenarios. Cost for MOP and TSP fertilizers were completely added for the sake of simplicity, although part was actually targeted to the maize crop. Urea was excluded as it was specifically targeted and applied to the maize stands. Selling crop residues or stover as fodder was not known in the area, therefore only the value of cowpea grains were included as benefits.

Prices for cowpea grain at harvest, ploughing, ridging, sowing, weeding, spraying, harvesting and shelling were based on information obtained from AEA's of both districts and confirmed with farmers.

All rates were converted to a per ha basis (Table 4). Labour for planting was paid for per day, while ploughing, ridging, spraying, and weeding was paid per acre. Harvesting was paid by giving 1/5 share of the total quantity that that person harvested. Both MOP and TSP were not available in or nearby the communities. Prices were therefore based on prices in agro-chemical stores in Tamale. MOP and TSP, unlike for example urea or compound fertilizers, were not subsidised at the time of research. All prizes were obtained in Ghana Cedi (GHC) and converted to United States dollar (US$) at a rate of $ 1 = GHC 1.998[1]. Interviews with households in both communities, as well as information from the AEA's in both regions showed that no crop residues were sold. Cowpea residues were therefore not incorporated as a possible source of income.

Table 4. Costs and revenue as used in the cost benefit analysis. Costs for material was based on prices from agro-chemical suppliers in Tamale. Cost for labour and the price of cowpea was based on information from AEA's and farmers in both areas.

Cost	Cost (GHC)[1]	Units	Needed ha^{-1}	Cost (GHC ha^{-1})	Cost (US$ ha^{-1})
Material					
TSP	80	50 kg	109 kg	204	102
MOP	85	50 kg	128 kg	102	51
Seeds	5	per kg	25.3 kg	127	63
Insecticide	13	per litre	1 litre	13	7
Labour					
Ploughing Kpatarr B.	35	per acre		86	43
Ploughing Bundunia	60	per acre		148	74
Ridging Kpatarr B.	35	per acre		86	43
Ridging Bundunia	60	per acre		148	74
Sowing	20	per acre		48	24
Weeding	30	per acre		74	37
Spraying	5	per acre		12	6
Harvesting	1/5 of the harvested quantity				
Shelling	7.5	per acre		19	9

Revenue	Price (GHC)	Units		Price (GHC Mg^{-1})	Price (US$ Mg^{-1})
Cowpea grain	250	100 kg		2500	1251

[1] Costs as mentioned in northern Ghana (1 acre = 0.4046 ha).

Interviews

In Kpatarr Bogu and Bundunia, 30 and 26 households were interviewed respectively. Interviews contained questions on: general household and farm characteristics, resource endowment, sources of income, the cropping system, food availability throughout the year, cowpea cultivation last year, and the interviewees' opinion of early cowpea cultivation, possibly in relay with maize as tested in the experiments. The complete survey can be found in Annex IV. If at first analysis answers were not completely clear, doubted or missing, a second visit to the household was made to clarify results.

Since only a limited number of households were interviewed, specific households were targeted (i.e. the richest and poorest) to include all types of households present in the communities. Interviews were held through a local translator. In Kpatarr Bogu this was a teacher of the local primary school who had also been active as a secretary of a local farmers group. For the interviews both farmers from this group and others were interviewed to obtain a representative sample of households from the village. In Bundunia the translator was the lead farmer of the community and as well the owner of the medium fertility field of the experiment. Both translators were well informed

[1] Rate for October 1st 2013, Central Bank of Ghana, accessed on November 14th 2013 http://www.bog.gov.gh/index.php?option=com_wrapper&view=wrapper&Itemid=303

about the community and therefore also acted as a guide to ensure that all types of households were interviewed.

In this report the words 'households', 'farming households', 'smallholders' and 'farmers' are used interchangeably. Usually one member of the household was interviewed, often the household head which was in most cases a man. There were some women headed households included and also sometimes it was not the household head who was interviewed. Households were defined as those people who belonged to the direct family of a household head. Generally a household consisted of a male household head, his wife and children. In Kpatarr Bogu polygamous marriages existed. If children of one household were married and had their own house (which could be in the same compound) and land, they were not seen as part of the household. Family member who lived in cities like Tamale, or in the south (Accra, Kumasi, Tema) and came from this same household, were only included as members of the households if they send remittances regularly.

Analysis of results

Results of the interviews were used to analyse in which context the cowpea-relay cropping system, as tested in the experiments, should fit. For example, to explore whether more nutritious food was needed in this part of the year, or whether there were already other legume crops harvestable. And also, whether this would differ for different types of households. The current (cowpea) cropping system was described to assess which changes would be needed to incorporate cowpea-maize relay cropping and whether this intensified cropping system would be feasible for different household types.

For analysis of food availability and cowpea cultivation, farmers were stratified in five farm types. Marenya and Barrett (2007) found that size of farm, value of livestock, off farm income, family labour supply, educational attainment and gender of the household head influenced uptake of new cropping technologies in western Kenya. Other studies found these or similar attributes were useful to construct farmer typologies that for example explained soil fertility management (Tittonell et al. 2010; Tittonell et al. 2005a), the risk for farmer to use new legume cropping technologies (Kamanga et al. 2010) or adoption of legume cropping technologies (Franke et al. 2014).

This research therefore used resource endowment and income distribution of different sources of income, to manually compose five different farmers groups. Based on the farm typologies as described by Tittonell et al. (2005a) and Tittonell et al. (2010) and adjusted for the specific circumstances in Northern Ghana. The number of households belonging to each farm type cannot be seen as representative for the whole community as specific households were targeted. The aim of this interview was primarily to explore how cowpea-maize relay cropping would fit for different farm types.

Results

Field selection

Field history

The estimated historical yield data in Kpatarr Bogu partly reflected the anticipated soil fertility gradient (Table 5). Comparing soya bean and groundnut yields, which were partly from different years, reflected the gradient between the fields. This variation can however also be an effect of other factors than soil fertility like seasonal variation or management. Maize yields for the medium and high fertility fields also reflected the gradient when comparing the 2010 yields. Maize was however also cultivated in 2012 in the high fertility field, resulting in an even lower yield than the 2010 yield of the medium fertility field. The lower maize yield in 2012 could indicate a reduced soil fertility in the high fertility field. In both the low and medium fertility fields legumes were cultivated in 2012, the year prior to the experiment, whereas in the high fertility field this was maize. No fertilizers were used in any of the experimental fields in the two years prior the experiment.

Estimated historical maize yields for Bundunia only reflected the anticipated soil fertility gradient for the high fertility field when comparing it with the low and medium fertility fields. The estimated maize yield for the high fertility field was however outstandingly high. The attainable yield for common maize varieties in northern Ghana is 4-5 Mg ha^{-1} according to Fosu et al. (2012). The high fertility field was close to the homestead and cultivated with millet in previous years. Organic fertilizers tend to be allocated to these millet fields close to the homestead and are therefore most fertile, according to the AEA and local farmers. This combined with a relatively high fertilizer application, explains at least partly the high maize yield and its perceived high fertility. Comparing maize yields of the low and medium fertility fields showed a higher yield for the low fertility field than the medium fertility field. Historical yield data did therefore not reflect the soil fertility gradient between the low and medium fertility fields. In the year prior the experiment no fertilizers were applied to the high fertility field, whereas especially the medium fertility field received a considerable amount of both sulphate of ammonia and NPK.

Soil analyses

Soil sample analyses generally did not reflect the soil fertility gradient in both locations (Table 6). The medium fertility field in Kpatarr Bogu had a higher total N, K, Ca, Mg and CEC than the high fertility field. Particle size distribution, plant available P and pH were very similar for the high and medium fertility field. The low fertility field had sometimes more favourable values than the high fertile field (Ca, Mg). Only O.C showed the expected gradient. In Bundunia the medium fertility field gave less favourable outcomes than the low fertile field for pH, K, Ca and Mg. Other parameters (O.C, N, CEC, particle size) showed no clear gradient either. Comparing Kpatarr Bogu and Bundunia showed that fields were less fertile in Bundunia than in Kpatarr Bogu, especially pH, O.C, N, K and CEC were lower. Fields were also more sandy in Bundunia.

Table 5. Field history of the experimental fields, obtained through interviews.

Fertility level	Size (ha) estimated	Year	Crop	Mineral fertilizer	Organic fertilizer	Total estimated yield (kg)[2]	Yield (kg/ha)	Pest and/or weed pressure
Kpatarr Bogu								
Low	0.81	2010	Cotton	-	-	550	700	-
Low	0.81	2011	Soya bean	-	-	300	350	-
Low	0.81	2012	Groundnut	-	-	450	550	-
Medium	0.40	2010	Maize	SA 50 kg, NPK 50 kg[1]	-	500	1250	-
Medium	0.40	2011	Groundnut	-	-	900	2200	Low weed infestation
Medium	0.40	2012	Soya bean	-	-	400	1000	-
High	0.40	2010	Maize	NPK 100 kg	-	700	1750	-
High	0.40	2011	Soya bean	-	-	800	2000	-
High	0.40	2012	Maize	-	-	400	1000	-
Bundunia								
Low	0.51	2010	Groundnut	-	-	500	1000	Moderate weed infestation
Low	0.51	2011	Maize	SA 100 kg	-	300	600	Moderate weed infestation
Low	0.51	2012	Maize	SA 100 kg	-	400	800	Moderate weed infestation
Medium	0.81	2010	Fallow	-	-	-	-	-
Medium	0.81	2011	Groundnut/bambara groundnut /local cowpea	-	-	500/200/50	600/250/50	Low weed infestation
Medium	0.81	2012	Maize	SA 150 kg, NPK 150 kg	-	100	100	Drought; Low weed infestation
High	0.20	2010	Millet	-	-	100	500	Low weed infestation
High	0.20	2011	Maize	SA 200 kg, NPK 300 kg	-	1300	6450	Low weed infestation
High	0.20	2012	Millet	-	-	100	500	Low weed infestation

[1] SA stands for sulphate of ammonia, NPK stands for 15-15-15 NPK fertilizer

[2] Yield was expressed in bags, basins or bales (cotton only) by the farmers. A bag was assumed to be 100 kg and a basin 25 kg. A bale of cotton was assumed to be 185 kg (Rowlet 2000).

Table 6. Soil parameters for the three different fertility levels in both locations.

Fertility level Method of extraction	pH 1:1 H_2O	O.C (%) Walkley & Black	N (%) Kjeldahl	P (ppm) Bray I	K (cmol/kg) Ammonium Acetate	Ca (cmol/kg) Ammonium Acetate	Mg (cmol/kg) Ammonium Acetate	CEC (cmol/kg) Ammonium Acetate	Sand (%)	Silt (%)	Clay (%)
Kpatarr Bogu											
High	5.7	0.94	0.07	3.4	0.22	1.17	0.57	6.01	60	30	10
Medium	5.6	0.82	0.08	3.1	0.23	1.36	0.58	7.27	62	28	10
Low	5.8	0.62	0.06	4.2	0.20	1.50	0.83	7.85	50	40	10
Bundunia											
High	5.2	0.43	0.04	3.9	0.15	1.54	0.63	4.04	82	12	6
Medium	4.1	0.35	0.05	6.6	0.11	0.65	0.18	4.00	86	8	6
Low	5.0	0.39	0.03	3.9	0.16	1.03	0.56	3.12	84	12	4

Rainfall during the season

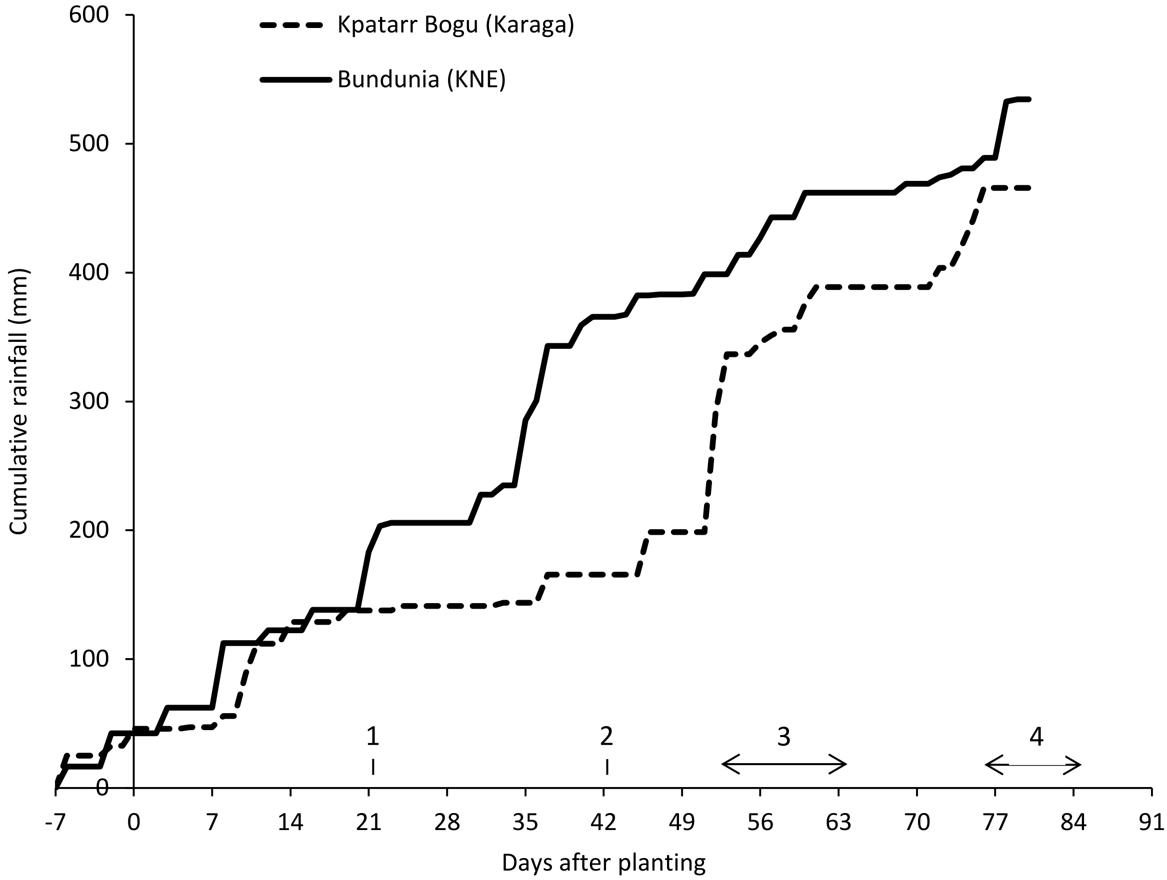

Fig. 5. Cumulative rainfall during the cropping periods in Kpatarr Bogu and Bundunia. Lines show the approximate dates of the 3wk (1) and 6wk (2) sowing of the relay maize into the cowpea. Arrows show the the approximate time of mid-pod filling (3) and final harvest (4).

Total rainfall was lower in Kpatarr Bogu (466 mm) than in Bundunia (535 mm) at 80 days after planting (DAP) (Fig. 5). Larger differences were however found half way the growing season due to a prolonged period of dry spells in Kpatarr Bogu. This dry spells coincided with the planting and emergence of maize in the 3wk treatments.

Emergence

Cowpea

Fertility differences were found to be significant in Bundunia (P=0.048) for emergence of cowpea. Most certainly this was not because of fertility level, but because of stray animals that had eaten a large part of the plants in the medium fertility field. Some plots were therefore almost completely re-sown in this field. Average emergence in Kpatarr Bogu was 90% with no significant differences between planting arrangements.

Maize

Planting arrangement showed a significant (P<0.001) effect on maize emergence in Kpatarr Bogu (Fig. 6). Sowing relay maize at six weeks was associated with significantly lower emergence than sowing at three weeks. Also, at six weeks, the 2×2 spacing resulted in significantly higher emergence rates than the 1×1 planting arrangements. Apart from the effect of planting arrangements there were several

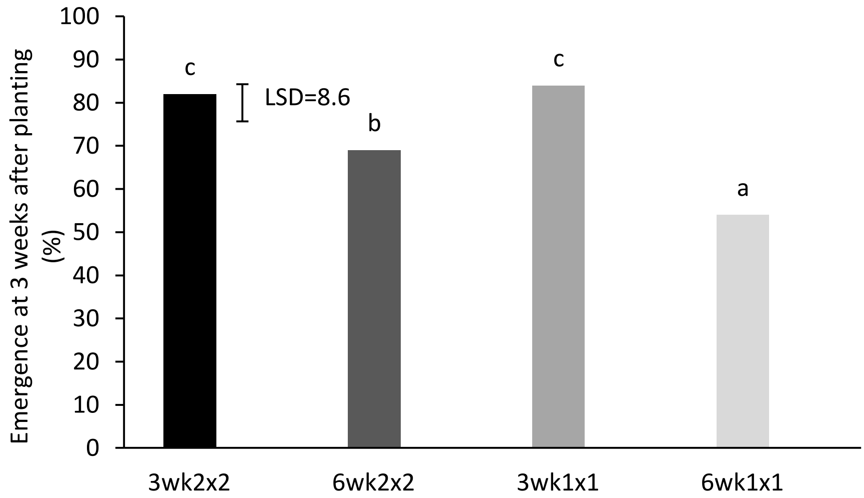

Fig. 6. Emergence of maize according to planting arrangements in Kpatarr Bogu. Significance of differences between means was tested with Fisher's LSD (α=0.05).
[1] Different letters represented significance between the means.

other reasons that were more likely to have caused this effect. Sowing at six weeks was in a rather dry soil, furthermore there were heavy rains just after emergence and also at that time re-ridging took place (before assessing emergence). At re-riding it was observed that plantlets were more easily observed in the 2×2 planting arrangement and therefore seemed to be less often damaged in the 2×2 than in the 1×1 planting arrangement. Re-ridging and dry spells factors probably had a negative effect on the emergence rate of maize at six weeks after sowing (Table 3, Fig. 5).

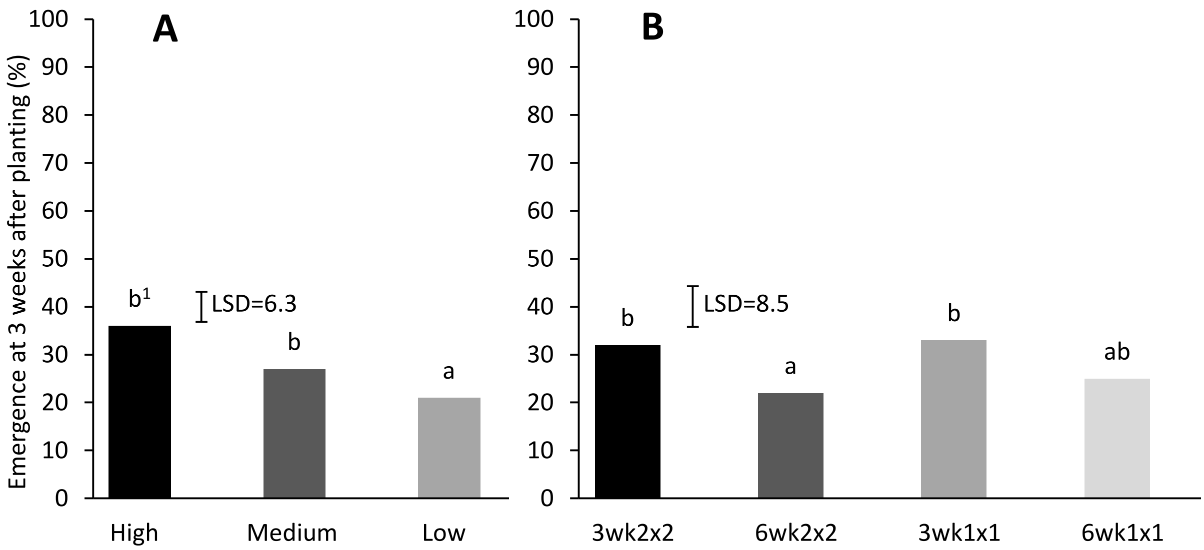

Fig. 7. Emergence of maize according to fertility levels (A) and planting arrangements (B) in Bundunia. Significance of differences between means was tested with Fisher's LSD (α=0.05).
[1] Different letters represented significance between the means.

Both fertility level (*P*=0.003) and planting arrangement (*P*=0.027) showed a significant effect on maize emergence in Bundunia. The relay maize in the low fertility field showed significant lower emergence than the high and medium fertility fields (Fig. 7A). Apart from fertility effects, this can have been due to high weed pressure in the low fertility field, which required intensive weeding. It was observed that several small maize plants were damaged during weeding activities. 6wk2×2 planting arrangement gave a significantly lower emergence than both 3wk planting arrangements

(Fig. 7B). Continuing rains at six weeks might have been affecting emergence due to seeds flushing away, rotting seeds or for instance water logging. Overall, emergence of the relay maize in Bundunia was very low and lower than in Kpatarr Bogu, probably due to the low quality of the maize (cv. Dodzi) seeds.

Mid-pod filling harvest

There was significant interaction between planting arrangements and fertility level for the total dry matter at mid-pod filling harvest of cowpea in Kpatarr Bogu (P=0.043). The interaction highly depended on low dry matter of the 6wk1×1 planting arrangement in the high fertility field. Interaction would not be significant if the lowest value of the four replicates of this treatments would be left out (P=0.053). This low biomass harvest in 6wk1×1 could not be explained by observed variations in the field, like pest for example. Results were therefore not deleted and interaction is still discussed as being significant.

Differences in TDM between the high and medium fertility fields were not significant except for 3wk2×2 and 6wk1×1 in the high fertility field. These had a significantly lower yield than 6wk2×2 and 3wk1×1 of the medium fertility field and 6wk2×2 and 3wk1×1 of the high fertility field, where by 3wk2×2 in the high fertility field was not significantly different from 6wk1×1 in the medium fertility field. The low fertility field had significantly lower yields than the other two fields except for 6wk1×1 which is not significantly different from 3wk2×2 and 6wk1×1 of the high fertility field.

There was no difference between planting arrangements within the medium fertility field. The high fertility field 6wk1×1 had a significantly lower yield than 6wk2×2 and 3wk1×1. The low fertility field had a significantly lower yield in 6wk2×2 than in 6wk1×1.

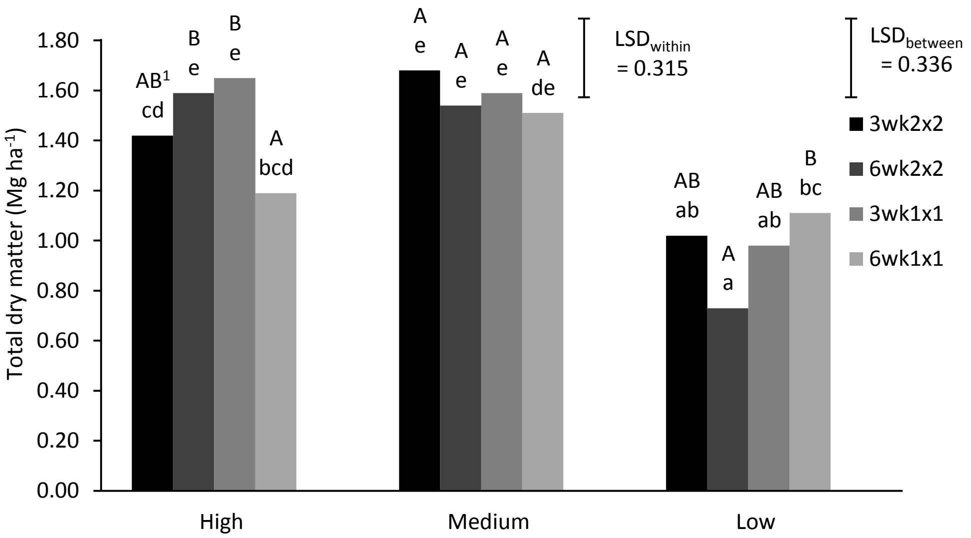

Fig. 8. Total dry matter of cowpea at mid-pod filling harvest in Kpatarr Bogu according to the different planting arrangements and the high, medium and low fertility fields. Significance of differences between means was tested with Fisher's LSD (α=0.05).

[1] Lower case letters represented significance between all means, uppercase letters represented significance within the fertility level.

TDM at mid-pod filling harvest showed no clear pattern, except for the low fertility field which generally had lower yields than the high and medium fertility fields. Differences found within fertility levels were unexpected. For example the 6wk1×1 was found to be lower than both the 3wk planting arrangements in the same field, while a higher yield would be expected as maize was planted at six weeks, which would cause less competition between the cowpea and the maize than when the maize was planted at three weeks. This means that, although interaction between fertility level and planting arrangements were found to be significant, no explanation based on the planting arrangements can be given.

Total dry matter of cowpea at mid-pod filling harvest in Bundunia showed no significant differences between any of the factors. Average total dry matter was found to be 1.73, 1.68 and 1.28 Mg ha^{-1} for the high, medium and low fertility fields respectively (data not shown). These yields were 10-20% higher than those in Kpatarr Bogu.

Nodulation

In both Kpatarr Bogu and Bundunia there were no significant differences in the average number of nodules. The average number of nodules per plant in Kpatarr Bogu were 18, 17, and 17 for the high, medium and low fertility fields respectively. In Bundunia the average number of nodules per plant were 9, 9 and 12 respectively.

In Kpatarr Bogu interaction between fertility level and planting arrangements on the average percentage of active nodules was found to be significant (P=0.013). Bartlett's test for homogeneity of variances was however also found to be significant (P=0.026), meaning that variances between planting arrangements were not equal across the fertility levels and planting arrangements. Therefore the results from the ANOVA test may not be reliable. Bearing this in mind, the differences are still discussed (Fig. 9).

Within fertility levels, 3wk1×1 in the high fertility field was significantly lower in percentage of active nodules than 6wk2×2 and 6wk1×1. Within the medium fertility field the percentage of active nodules was significantly lower in 3wk2×2 than in 6wk2××2. For the low fertility field there were no significant differences in active nodules.

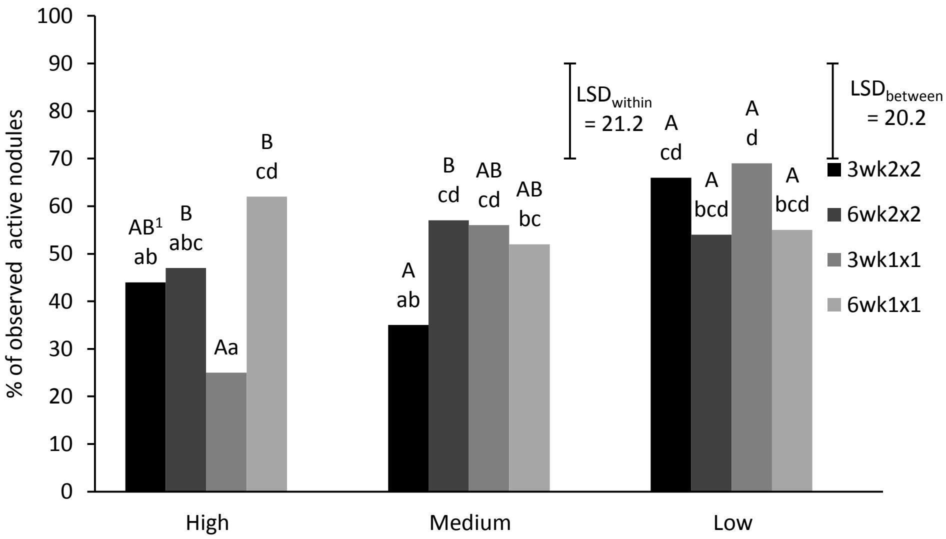

Fig. 9. Percentage of active nodules in Kpatarr Bogu according to the different planting arrangements and fertility levels. Significance of differences between means was tested with Fisher's LSD (α=0.05).

[1] Lower case letters represented significant difference between all the means and uppercase letters represented the significance within a fertility level. No letters means that there were no significant differences found between the means.

Differences in active nodules found between planting arrangements 3wk2×2 and 3wk1×1 of the low fertility field, 6wk2×2 and 3wk1×1 of the medium fertility field and 6wk1×1 of the high fertility field were not significant. The here for mentioned planting arrangements had significantly higher percentage of active nodules than 3wk2×2, 3wk1×1 of the high fertility field and 3wk2×2 of the medium fertility field, whereas there was no significant difference between these three planting arrangements. The planting arrangements 6wk2×2 of the high fertility field, 6wk2×2 and 6wk1×1 of the low fertility field and 6wk1×1 of the medium fertility field did not significantly differ from all other planting arrangements, except for two treatments. 3wk1×1 of the high fertility field was significantly lower and 3wk1×1 of the low fertility field was significantly higher in percentage of active nodules than the afore mentioned planting arrangements. Although differences in percentage of active nodules were sometimes significant, no clear pattern emerged from this.

Percentage of active nodules in Bundunia showed no significant differences for any of the factors tested. Average percentage of active nodules per plot was 36% for the high, 27% for the medium and 30% for the low fertility field.

A clear difference in nodulation between Kpatarr Bogu and Bundunia was found. Using location as main treatment and fertility level as subplot in a split-plot analysis showed that Bundunia had a significantly lower average number of nodules per plant and a lower percentage of active nodules than Kpatarr Bogu (Table 7). Bartlett's test for homogeneity of variances was however also found to be significant for average number of nodules per plant, indicating that results from the ANOVA test may not be reliable.

Table 7. Average number of nodules and average percentage of active nodules for both sites. Significance of differences between site means was tested with Fisher's LSD (α=0.05).

	Average # of nodules per plant	Average active % of nodules
Kpatarr Bogu	17	52
Bundunia	10	31
LSD	3.2	18
P	0.005	0.035
Homogeneity *P*	0.070	0.032

Final yield

In Kpatarr Bogu the low fertility field had a significantly lower cowpea grain yield than the high and medium fertility fields (*P*=0.019). Between the high and medium fertility field no significant differences were found (Table 8). The different planting arrangements (*P*=0.645) or interaction between fertility levels and planting arrangements (*P*=0.319) were insignificant. Both total biomass (Fig. 10) and stover + empty pods (not shown) in Kpatarr Bogu at final harvest showed no significant difference for any factor.

Cowpea grain yield in Bundunia also showed significant differences between the fertility levels, whereby the high fertility field had a significantly (*P*<0.001) higher yield than the medium and low fertility fields (Table 8). Different planting arrangements (*P*=0.155) or interaction between fertility level and planting arrangement (*P*=0.519) showed no significant differences.

Table 8. Final cowpea grain yields (Mg ha^{-1}) in Kpatarr Bogu and Bundunia for different planting arrangements and fertility levels. The average over the planting arrangements of the different fertility levels was found to be significant for both Kpatarr Bogu and Bundunia. Significance of differences between means was tested with Fisher's LSD (α=0.05).

Fertility level	Planting arrangement				Average over planting arrangements
	3wk2×2	6wk2×2	3wk1×1	6wk1×1	
Kpatarr Bogu					
High	0.82	0.66	0.71	0.61	0.70 b[1]
Medium	0.72	0.87	0.68	0.76	0.76 b
Low	0.63	0.48	0.53	0.63	0.57 a
$P_{\text{fertility level × planting arrangement}}$					0.319
$P_{\text{planting arrangement}}$					0.645
$P_{\text{fertility level}}$					0.019
$LSD_{\text{fertility level}}$					0.120
Bundunia					
High	1.32	1.18	1.11	1.22	1.21 b
Medium	1.03	0.61	0.89	0.72	0.81 a
Low	0.73	0.66	0.69	0.73	0.70 a
$P_{\text{fertility level × planting arrangement}}$					0.519
$P_{\text{planting arrangement}}$					0.155
$P_{\text{fertility level}}$					<0.001
$LSD_{\text{fertility level}}$					0.159

[1] Different letters represent significance between the means within locations.

Total above ground biomass of cowpea in Bundunia showed significant differences between the different fertility levels (P=0.021), whereby the high fertility field had a significantly higher yield than the low fertility field (Fig. 10). This was in contrast with the above described grain yield, where the high fertility field also had a significantly higher yield than the medium fertility field. Refilling of the medium fertility field made that a considerable part of its plots was also harvested later than the high and low fertility fields. It seemed from observations that due to different weather conditions (more rain and lower temperatures) later in the season, these refilled plants made more vines than the earlier sown plants. Stover + empty pods at final harvest showed no significant difference for any factor (not shown).

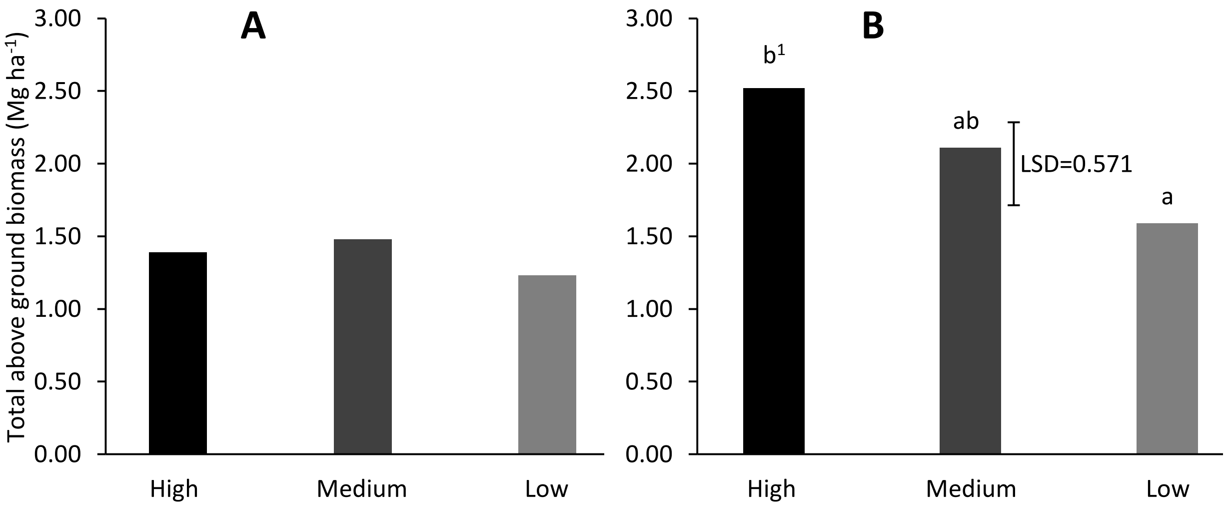

Fig. 10 Final total aboveground biomass yield of cowpea in Kpatarr Bogu (A) and Bundunia (B). Fertility level (A) was found to be significant in Bundunia (P=0.021) and not in Kpatarr Bogu (P=0.070). Significance of differences between means was tested with Fisher's LSD (α=0.05).
[1] Different letters represented significance between the means.

N-concentration and %N fixed

In order to make partial N-budgets a literature study was conducted to obtain estimates for N-concentration of grain and stover and for the percentage N from N_2-fixation. It was also tried to find specific values for N-concentration of pods and stover at maximum bio mass (mid or late pod filling stage) and at final harvest for grains, stover and remains of pods after shelling. This as a plant tends to accumulate more N in its grains when maturing than in earlier physiological stages like mid-pod filling stage for example. There was however no study found that stated both N-concentrations at maximum biomass and final harvest. N-concentrations from different studies, derived at either maximum biomass or final harvest, differed between each other as much as between these two different moments of harvest (Table 9). Furthermore it was not always completely clear at which stage a harvest took place in these studies, therefore an average was determined based on all data found. The same was done for %N fixed through N_2-fixation (Table 9). Average N-concentration of grain was found to be 3.8%, that of stover 2.5%. Cowpea on average fixed 70% of plant N through N_2-fixation.

Table 9. Literature review of N concentration of cowpea grain and stover and %N fixed through N_2-fixation.

	N-concentration (%)		%N fixed	Location	Mentioned harvest stage
	Grain	Stover			
Adjei-Nsiah et al., 2008[1]	3.4	2.3	71	Southern Ghana	Late podding
Awonaike et al., 1990	3.6	1.9	61	Nigeria	Physiological maturity
Bado et al., 2006			52	Burkina Faso	Physiological maturity
Carsky et al., 2001	3.6	2.2		Northern Nigeria	Final harvest
Carsky et al., 2001	3.4	1.8		Northern Nigeria	Final harvest
Dakora et al., 1987			89	Northern Ghana	Final harvest
Eaglesham et al., 1982			69	Nigeria	Physiological maturity
Ebanyat et al., 2010			78	Uganda	50% flowering
Makoi et al., 2009[1]	4.0	3.3	50	South Africa	Early podding
Manenji, 2011	4.5	3.1		Zimbabwe, Mudzi	Physiological maturity
Manenji, 2011	4.4	3.0		Zimbabwe, Murehwa	Physiological maturity
Naabe et al., 2009			79	North West Ghana	Late pod filling
Pule-Meulenberg et al., 2010			75	Northern Ghana	46 DAP
Pule-Meulenberg et al., 2010			75	South Africa	46 DAP
Rusinamhodzi et al., 2006			78	Zimbabwe	Physiological maturity
Sanginga et al., 2000			70	Nigeria	Mid-pod filling
Vesterager et al., 2008			60	Tanzania	Physiological maturity
Average	3.8	2.5	70		
Range	3.4-4.5	1.8-3.1	52-89		

[1] N content of the grains were in this case not of the grains but of the whole pods

Partial N-budgets

Table 10. Inputs used for partial N-budgets of cowpea based on yields at mid-pod filling stage and maturity and N-concentration and %N fixed from literature.

		Kpatarr Bogu			Bundunia		
	Fertility level	High	Medium	Low	High	Medium	Low
Biomass at mid-pod filling (Mg ha^{-1})	Stover	1.00	0.99	0.64	1.27	1.35	0.89
	Pods	0.46	0.59	0.32	0.45	0.33	0.39
	Total	1.46	1.58	0.96	1.72	1.68	1.28
Biomass at maturity (Mg ha^{-1})	Stover	0.59	0.62	0.57	1.13	1.18	0.78
	Pods	0.80	0.86	0.66	1.32	0.93	0.81
	Total	1.39	1.48	1.23	2.45	2.11	1.59
N at highest total biomass (kg ha^{-1})	Stover	22	22	14	32	34	23
	Pods	25	30	25	46	32	30
	Total above ground	47	52	40	79	66	52
	Whole plant	68	74	57	113	94	74
N-fixed (kg ha^{-1})	Above ground	33	36	28	55	46	36
	Whole plant	47	52	40	79	66	52
Biomass at maturity (Mg ha^{-1})	Stover	0.59	0.62	0.57	1.13	1.18	0.78
	Grains	0.62	0.67	0.50	1.01	0.71	0.62
	Empty pods	0.18	0.19	0.16	0.30	0.21	0.19
N at final harvest (kg ha^{-1})	Grains	24	26	19	39	27	24
	Empty pods	5	5	4	8	5	5
	Stover	15	15	14	28	30	20

Crop production was a major factor determining N-budgets (Table 10 and Table 11). The higher total biomass and stover and grain yields at final harvest in Bundunia resulted in more negative budgets in Scenario 1 and more positive budgets in Scenario 3 and 4 than in Kpatarr Bogu, which had lower yields. The fertility levels showed this pattern as well. With higher yields, budgets became generally lower in Scenario 1 and higher in scenarios 3 and 4.

Scenarios 3 and 4 of the high and medium fertility field in Bundunia gave very similar budgets, even though total biomass yield in the high fertility field was higher. Grain yield at maturity of the medium fertility field in Bundunia was however lower in proportion to its total biomass than in the other fertility levels, resulting in relatively high N-budgets.

Table 11. Partial N-budgets (kg ha^{-1}) of cowpea as an early relay crop for the three fertility levels in Kpatarr Bogu and Bundunia based on the four different scenarios. The possible range of the N-budgets using lowest and highest %N fixed through N_2-fixation found from literature is shown between brackets.

	Kpatarr Bogu			Bundunia		
	High	Medium	Low	High	Medium	Low
Scenario 1[1]	-10 (-18 – -1)	-10 (-19 – 0)	-10 (-17 – -2)	-20 (-34 – -5)	-16 (-28 – -4)	-12 (-21– -2)
Scenario 2	4 (-8 – 17)	6 (-7 – 20)	2 (-8 – 13)	4 (-16 – 26)	4 (-13 – 22)	4 (-9–18)
Scenario 3	19 (7 – 32)	21 (8 – 36)	16 (6 – 27)	32 (12 – 54)	33 (16 – 51)	24 (10–38)
Scenario 4	14 (2 – 27)	16 (3 – 30)	11 (1 – 22)	22 (2 – 44)	21 (4 – 39)	16 (3–30)

[1] Scenario 1 = ((%N fixed × above ground plant N)/100) - ($N_{residues}$ + N_{grains})
Scenario 2 = ((%N fixed × whole plant N)/100) - ($N_{residues}$ + N_{grains})
Scenario 3 = ((%N fixed × whole plant N)/100) - N_{grains}
Scenario 4 = ((%N fixed × whole plant N)/100) - ($N_{residues}$ + N_{grains}) + ($N_{residues}$ × 0.5_{manure})

Scenario 1 showed that not taking into account belowground plant N always resulted in negative budgets if grains and stover were both harvested and taken out of the field. Taking below ground plant parts into account (Scenario 2), gave low, positive values. This can be the case if farmers for example take out the stover for fodder and not return the manure produced from this stover to the same field. Leaving residues in the fields or return them as manure (scenarios 3 and 4) resulted in highest N-contributions. The range of possible outcomes using lowest and highest values of %N fixed through N_2-fixation found in literature showed that budgets would always be negative for Scenario 1. Scenarios 3 and 4 always gave positive N-budgets, even with the lowest %N fixed through N_2-fixation found in literature for cowpea.

Before compiling the N-budgets, total biomass at mid-pod filling stage and that at maturity was first compared for each plot. Total N-fixed was then based on the highest total biomass measured. It was found that the highest maximum biomass was mostly measured at maturity and not at mid-pod filling stage (Table 12).

Table 12. Percentage of plots with the highest total biomass at mid-pod filling stage or maturity.

	Mid-pod filling	Maturity
Kpatarr Bogu	38	63
Bundunia	23	77
Average	30	70

Partial financial budget analysis ($)

As with the partial N-budgets, the partial financial budget analysis was based on the averages per fertility level as only fertility level significantly affected final cowpea grain yield and costs did not differ between planting arrangements (Table 13).

Table 13. Partial budget analysis for adding cowpea as an early relay crop before maize, using two scenario's

		Kpatarr Bogu			Bundunia		
	Fertility level	High	Medium	Low	High	Medium	Low
Common attributes (US$ ha^{-1})	Grain yield (Mg ha^{-1})	0.70	0.76	0.57	1.21	0.81	0.70
	Total revenue	874	950	708	1511	1016	877
	Costs of materials	223	223	223	223	223	223
Scenario 1 (US$ ha^{-1})	Labour	266	281	233	393	294	266
	Total cost	489	504	456	616	517	489
	Net revenue	385	446	253	894	498	387
	BC ratio	1.79	1.88	1.55	2.45	1.96	1.79
Scenario 2 (US$ ha^{-1})	Labour	381	396	348	570	268	444
	Total cost	605	620	571	794	492	667
	Net revenue	270	330	137	717	524	210
	BC ratio	1.43	1.52	1.22	1.89	1.43	1.30

[1] Scenario 1 included only costs that were explicitly needed for adding cowpea as an additional crop to the maize cropping system, thus only cost for materials (seed, TSP and MOP fertilizer and insecticide), sowing and insecticide application (2x), one time extra weeding, harvesting and shelling were included. Scenario 2 included all cost that were needed for cowpea cultivation, thus cost of ploughing, making the ridges, materials (seed, TSP and MOP fertilizer, insecticide), sowing and application (2x), weeding (2x), harvesting and shelling were included. See Table 4 for detailed cost.

Results of the partial budget analysis largely reflected the variation in final cowpea grain yields. Although, labour cost were higher with a higher grain yield (labourers were paid 1/5 of their harvest), total revenue was also higher. Higher labour cost for land preparation in Bundunia were well compensated by higher grain values. Net revenue and BC ratios were thus more favourable in Bundunia than in Kpatarr Bogu.

In Kpatarr Bogu, net revenue and BC ratio for the medium fertility field was highest for both scenario's, followed by the high and low fertility fields. Bundunia showed most favourable values for the high fertility field due to its high grain yield, the medium and low fertility field showed values closer to each other and quite lower than the high fertility field. Overall there seemed to be a trend that high fertility fields gave a more favourable BC ratio than low fertility fields.

Comparing the two scenario's gave, as expected, better outcomes for Scenario 1 than for Scenario 2. In both scenario's net revenues were positive for all fertility levels. In Bundunia the BC ratios in Scenario 1 for the high and medium fertility fields were higher than or close to 2, other BC ratios for Scenario 2 were all above 1.5. Looking at BC ratios for Scenario 2 shows all values between 1.2 and 1.5, except for the high fertility field in Bundunia, which was 1.89.

Interviews

Two kinds of cowpea were distinguished during the interviews. The indeterminate varieties that had many vines and thereby covered a large area per plant and as far as observed, produced brown grains. The indeterminate varieties seemed to be an integral part of the cropping system. In Bundunia these indeterminate varieties could be found in almost every household, mixed with millet and leafy vegetables, in a field close to the homestead. This type of cowpea was also intercropped with groundnut and bambara groundnut (*Vigna subterranea* (L.) Verdc.). In Kpatarr Bogu these indeterminate varieties were mixed with millet and maize. The other kind of cowpea was the more erect and more determinate varieties which produced white or creamy grains and were only grown as a sole crop. These were generally seen as new varieties and comparable with cv. Songotra. The white and more determinate varieties are referred to as 'erect cowpea' hereafter, whereas the more indeterminate, brown type is called 'local cowpea' from now on.

Farm types

Cropping and livestock were the most common sources of income in both villages. Salaried jobs were of major importance in Bundunia. The village was about 5 km from the district capital, Navrongo, with some of its main institutes (university and schools) on the road towards the village. Another important source of off-farm income came from the rice irrigation area close to the village (3 km). Not only for farmers that had fields in the irrigation area, but also for others to do casual labour (year round) and for women to sell food or local liquor. These small business related to the irrigation area resulted in a high importance score for other business (Table 14).

In Kpatarr Bogu there were not such major sources of off-farm income. There seemed to be less demand for casual labour, especially throughout the year, although in total more households took part in casual labour (Table 14). Other sources of off-farm income were transport of goods by donkey cart, searching and cleaning of shea nuts and some petty trade. Selling of farm produce from Kpatarr Bogu in the regional markets of Walewale (56 km), Savelugu (55 km) and the main market of northern Ghana, Tamale (81 km) was typical for Kpatarr Bogu. The primary school was the only public institutes providing jobs within the village. Remittances seemed somewhat more important in Kpatarr Bogu.

The interviewed households could be grouped in similar farm types for both villages (Table 15). Only land area differed. In Kpatarr Bogu more land was available, even the smallest farmers estimated to own about 5 ha. For the same group in Bundunia this was about 1 ha. Instead of farm land, labour or inputs seemed to be limiting in Kpatarr Bogu. The area cropped annually was also asked for. This showed to be an important factor for the different farm types and was therefore included.

Table 14 Sources of income and importance of these income sources for the two villages.

	Kpatarr Bogu (n=30)		Bundunia (n=26)	
	% of households	Importance score[1]	% of households	Importance score[1]
Cropping	100	1.1	100	1.3
Livestock	90	2.2	85	2.6
Casual labour	67	3.8	35	3.1
Other business 1[2]	57	3.4	50	2.2
Remittances	37	3.4	27	3.1
Trading	13	2.3	4	1.0
Salaried job	3	1.0	31	1.5
Other business 2[2]	0	-	8	4.0
Pension	0	-	0	-

[1] The importance score is the average of the importance that interviewed households gave to a source of income in comparison with other sources of income, whereby 1=the most important source, 2= second most important, etc. A maximum of five most important sources of income were recorded and compared.

[2] Other business were those that did not fit in one of the other categories, for example petty trade, a bar, beer brewing, a tractor for ploughing, a donkey cart, shea nut collecting, groundnut shelling etc.

Especially for the somewhat 'better-off' farm types 3 and 4, cropped area in Kpatarr Bogu was similar to the total area owned in Bundunia. There thus seemed to be less differences than at first hand anticipated. Cropped area was however not asked for in Bundunia.

Table 15. The five farm types as developed to characterize the interviewed households in Kpatarr Bogu (30 households) and Bundunia (26 households).

Farm type	Main source of income	Possessions	Livestock	Land owned	
				Kpatarr Bogu	Bundunia
1	Labour; sometimes little petty trade	Maybe a bicycle and/or small radio	None or less than 3 goats/sheep	5 ha (3 ha)[1]	1 ha
2	Services; petty trade	One or more bicycles	~10 goats/sheep, sometimes 2 cattle instead	10 ha (3 ha)	1-2 ha
3	Small enterprises; some salary; trading	Bullock plough, donkey cart or motorbike	~15 goats or sheep or about 5 cattle instead	10 ha (6 ha)	1-5 ha
4	Farm produce; farm services; trading	Tractor e.g.	>15 goats/sheep and/or more than 5 cattle	18 ha (10 ha)	10 ha
5	Salaried job	Motorbike, TV etc.	5-20 goats/sheep and 0-5 cattle	-	1-5 ha

[1] In Kpatarr Bogu also area cultivated was asked as not the area of land owned, but inputs and labour.

The most important factors that determined in which farm type a household would fit differed between the two villages. In Bundunia, the number of cattle owned played a major role. In Kpatarr Bogu cattle were less present, but instead diversity in farm types was seen in ownership of assets like bicycles, motorbikes, tractors or other implements. Type 5, which was mainly determined by having a salaried job as main source of income, was scarce in Kpatarr Bogu, as only one interviewed household belonged to this group (Table 16).

Fertilizer use (not shown) was taken into account when other attributes were not showing a clear pattern. However, as fertilizer use was only recorded for last year, it was not always related to farm type. Fertilizers were used more in Bundunia, where even the farmers of Type 1 and 2 bought some fertilizer. None of the households of Farm Type 1 in Kpatarr Bogu bought fertilizer and of Type 2 only half of them bought it.

Results of farm types 1 and 2 were combined to describe results for 'Poorer' households and those of farm types 4 and 5 for describing results of somewhat richer or 'better-off' households. These groups were used for some of the following analyses.

Table 16. Number and percentage of households as categorized in the different farm types

Farm type	Kpatarr Bogu		Bundunia	
	#	%	#	%
1	4	13	2	8
2	12	40	9	35
3	7	23	8	31
4	6	20	3	12
5	1	3	4	15
Total	30		26	

Food availability and shortage

In order to understand the need for intensified cropping systems, questions were asked about food availability and scarcity. The percentage of households having food shortage and households depending on the market throughout the year are shown in Fig. 11. If households were able to buy food from savings or by selling livestock, they were still seen as food sufficient. Only when there was very few livestock this was still seen as having difficulties to buy food and therefore having a shortage of food.

Kpatarr Bogu

Generally 'poorer farmers' were most food insecure. The overall average showed that the peak of food shortage was in June and July where 50% of the interviewed households did not have enough food to feed the family. A difference between the somewhat 'better-off' farmers and the 'poorer' was that the 'better-off' had their peak of food shortage in June, while food shortage continued to rise for the 'poorer' household in July, after which it dropped.

July was the month when on average most food was bought in the market. On average, the 'poorer' households depended less on food from the market and more on their own produce than the 'better-off' households, however, during the peak of food shortage this changed. In June and July, the 'poorer' depended more on the market than the 'better-off' households.

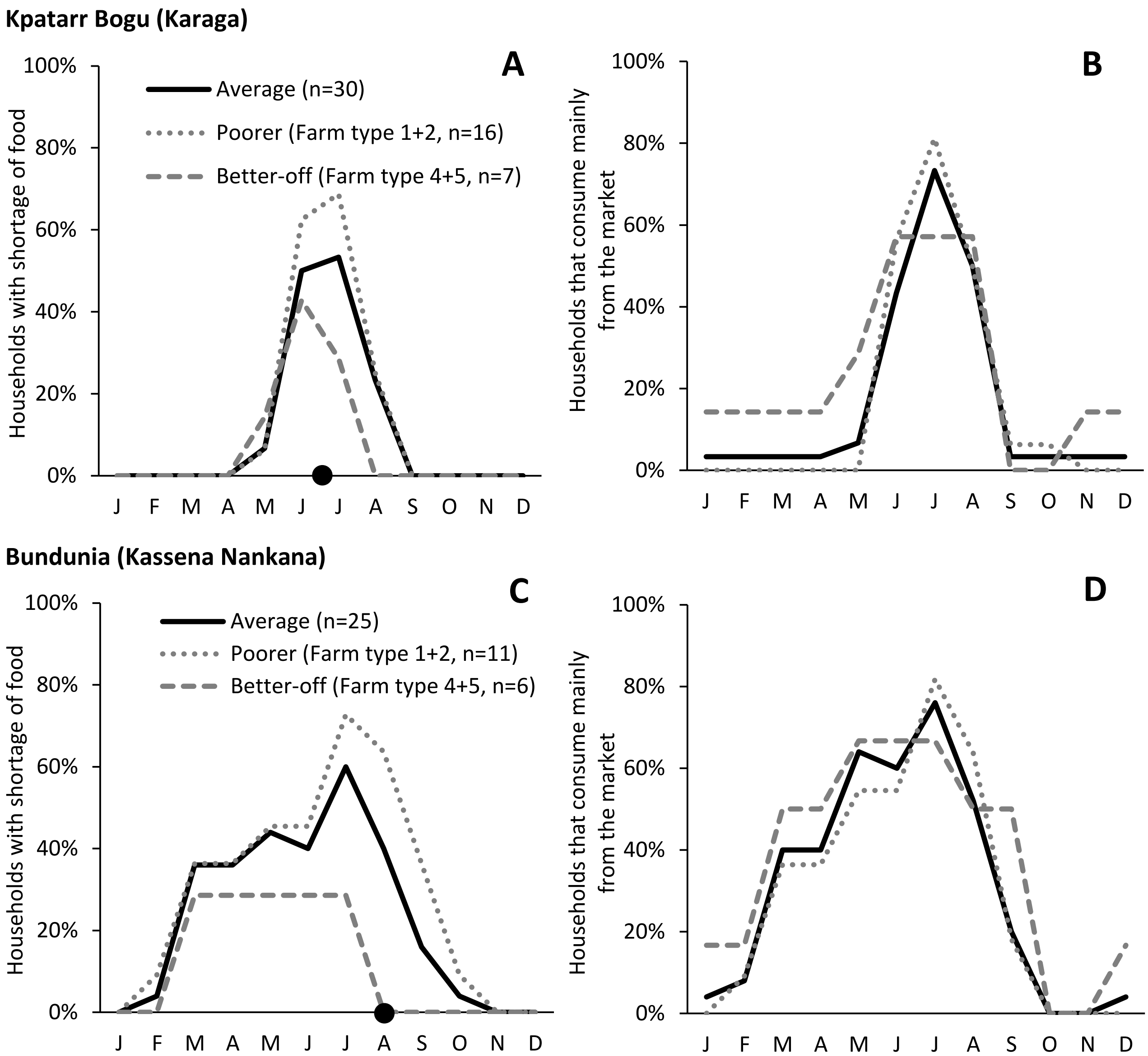

Fig. 11 Food sufficiency (A and C) and dependency on the market (B and D) based on farmers interviews for the two different villages. For the 'poorer' farmers, type 1 and 2 and for the richer farmers type 4 and 5 were taken together. The approximate moment of early cowpea maturity when planted with the early crops, is depicted with a black dot on the X-axis (C and D)

Bundunia
In Bundunia food shortage started earlier than in Kpatarr Bogu, already in March around one third of the households did not have enough food to feed the family. The peak of food shortage was in July when on average 50% of the household did not have enough food. Similar to Kpatarr Bogu, food shortage remained high in the following month for the poorer farmers, whereas for the 'better-off' households shortage already sharply decreased in August.

Most food was bought in the market from May to July, with a peak in July, when on average 69% of the households bought its food from the market. 'Better-off' households relied more on the marked than the 'poorer' households. However, in July when food shortage was biggest, a higher percentage of the 'poorer' households bought most of their food from the market.

Cropping calendar

Kpatarr Bogu
The cropping calendar of Kpatarr Bogu showed that groundnut and maize were planted as early crops at the onset of the rainy season in early April and harvested early August (Table 17). Maize and groundnut were mostly combined as a mixed-crop. Maize was sown again in June when rains were well established. Other common crops like soya bean, millet, rice and local cowpea were sown in May or June and harvested at the onset of the dry season in November. Yam planted at the onset of the dry season was harvested in August and thereby also one of the crops harvested early in the season.

Erect cowpea was planted as one of the late crops and cultivated by 23% of the households, only as a sole crop. Local cowpea was cultivated by 13% of the farmers and always mixed-cropped with either millet or maize. The percentage of farmers cultivating cowpea was much lower than the percentage cultivating other legumes like groundnut (97%) and soya bean (80%). Erect cowpea and soya bean were weeded less often than for instance maize, millet, yam and legumes intercropped with maize or millet.

Bundunia
The cropping calendar in Bundunia was different from that in Kpatarr Bogu. Crops planted first were late and early millet and local cowpea. These crops were always mixed, often together with vegetable crops like okra or leafy vegetables. Early millet was harvested first, in early August. Leaves of the local cowpea and the leafy vegetables were also harvested around that time and used as main ingredient in soups. Grains of local cowpea and late millet were harvested at the onset of the dry season. Dry-land rice was also sown as an early crop, in late May and harvested early September. It was cultivated by 15% of the households. Irrigated rice seemed to be an important crop, not only because 35% of the households cultivated it but also because it can be planted twice a year. The dry season crop was harvested early July, at the start of the rainy season and in the middle of the lean season. Maize was cultivated by 96% of the households. Like groundnut it was sown early June. Maize was harvested early October. Groundnut was the second most cultivated crop and harvested late September.

Erect cowpea was cultivated by 38% of the interviewed households in Bundunia, only as a sole crop. It was planted in early August, latest of all rain-fed crops and harvested early October. Groundnut and erect cowpea were weeded on average 1.5 and 1.3 times respectively. This was less than for example maize, which was weeded 2.0 times and late millet, weeded 2.8 times. Since local cowpea was often intercropped with millet, it was weeded as many times. Rice was weeded only 1.5 times and sprayed at least once with selective herbicides.

In both areas, planting a 2-2.5 month (erect) cowpea variety at the same time as the other early crops, would result in earlier availability of food from the own farm (Fig. 11). Planting erect cowpea with the early crops (late-May) in Bundunia would result in maturity around early August. It would be the only early legume, resulting in more nutritious food, early in the season. In Kpatarr Bogu planting would be early April and maturity mid-July, about one month earlier than groundnut.

Table 17. Cropping calendar based on farmers interviews. Sowing and harvesting dates were obtained by taking the median of mentioned dates of this management practice in an average year.

	Households cultivating the crop (%)	Times of weeding	January	February	March	April	May	June	July	August	September	October	November	December
Kpatarr Bogu (Karaga, n=30)														
Groundnut	97	2.0												
Soya bean	80	1.5												
Maize 1	77	2.0												
Maize 2	77	2.0												
Millet	43	2.5												
Yam 1	43	3.5												
Yam 2	43	3.1												
Rice (dry land)	40	1.5												
Cowpea (erect)	23	1.3												
Cowpea (local)	13	2.3												
Cassava	10	2.0												
Bambara groundnut	7	2.0												
Watermelon	7	1.5												
Bundunia (Kassena Nankana, n=26)														
Maize	96	2.0												
Groundnut	92	1.5												
Millet (late)	81	2.8												
Cowpea (local)	81	2.7												
Millet (early)	65	2.1												
Cowpea (erect)	38	1.3												
Rice (Irrigated)	35	1.5												
Bambara groundnut	19	1.8												
Rice (dry land)	15	2.0												
Soya bean	12	2.0												

Cropping systems

Different village and farm layouts were observed in Kpatarr Bogu and Bundunia. In Kpatarr Bogu all houses of the village were grouped around the Gushiegu – Pigu road leading through the village, with smaller dirt-roads and paths branching from road to the surrounding fields. Small ruminants were kept around the homestead. The few farmers in Kpatarr Bogu who owned cattle, did not keep them themselves. Cattle herding was 'outsourced' to the Fulani people, a tribe of herdsmen that stayed outside of the village and were not part of this research. In Bundunia the houses were scattered over the landscape. Land belonging to a household was typically situated around the house, whereby the millet-mixed cropping field was closest to the house and other crops further from the house. Cattle and other ruminants were kept around the homestead.

Crop rotations of cereals and legumes were more common in Kpatarr Bogu than in Bundunia. (Fig. 12). Intercropping of legumes with cereals was more common in Bundunia, which was mainly caused by the millet-cowpea cropping system. In both places legume-legume rotations were reported. Cereal-cereal rotations were more common in Bundunia than in Kpatarr Bogu. Fallow was often mentioned in rotations in Kpatarr Bogu, but only reported by a few somewhat 'better-off' farmers in Bundunia

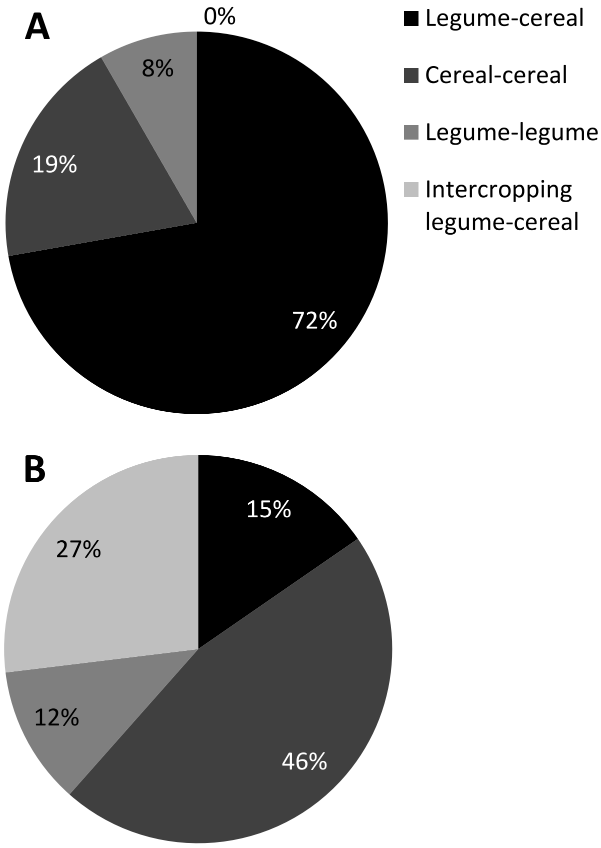

Fig. 12. Importance of crop rotations in Kpatarr Bogu (A) and Bundunia (B). Legume-cereal means a crop rotation including cereals and legumes, cereal-cereal means a rotation of only cereals, legume-legume means only legumes in rotation, while intercropping legume-cereal means only intercropping and no rotation with sole crops.

In Kpatarr Bogu tractor (disc) ploughing was most often used for tillage in combination with flatland farming. In Bundunia ridges were more common, often made by bullock ploughs, sometimes by tractors or with hand-hoes. Disc ploughing was less common in Bundunia.

Cowpea cultivation

Kpatarr Bogu

In Kpatarr Bogu 37% of the households cultivated cowpea, which was either the local type (20%), or the erect type (17%) (Table 18). Of those cultivating the erect type all were selling at least part of their cowpea yield. For the local cowpea, 5 out of the 6 households used it for own consumption only. Yield was estimated to be higher on average for the erect type (364 kg ha^{-1}) than the local type (121 kg ha^{-1}).

Table 18. Number of households cultivating cowpea according to farm type. Cowpea is divided into the local and the erect type. Between brackets the total number of households belonging to each farm type is shown.

Farm type	Kpatarr Bogu			Bundunia		
	Local	Erect		Local	Erect	
1	1	-	(4)	1	1	(2)
2	3	1	(12)	9	1	(9)
3	1	2	(7)	7	3	(8)
4	1	2	(6)	3	2	(3)
5	-	-	(1)	1	2	(4)
Total	6	5	(30)	21	9	(26)

Table 19. Cowpea residue use for all cowpea fields in both villages according to the two cowpea types.

	Kpatarr Bogu		Bundunia	
	Left on the field	Used as fodder	Left on the field	Used as fodder
Erect	5	0	4	5
Local	3	5	17	5

Most households cultivated cowpea on a fertile field, some on a poor field. Fertilizer (Ammonia of sulphate) was only applied by one farmer in a local cowpea-maize field and therefore only targeted to the maize. Two farmers applied manure to their fields, for one it was on erect cowpea, the other was on a mixed millet/local cowpea field. All farmers left residues of erect cowpea in the field. For the local type, three farmers used it as fodder, the other three left it in the field (Table 19). One farmer mentioned the fear that the insecticide used for erect cowpea would affect livestock if its fodder would be fed to them.

On average the local cowpea was estimated to have a pest score of 3, while the erect was scored 2 out of 5, where 5 is no yield due to pests and 1 means no pest damage at all. On average, insecticide was applied four times on the erect cowpea. None of the households applied insecticide on the local cowpea type.

Bundunia

Cowpea was more common in Bundunia. 81% of the households cultivated local cowpea, all used intercropping. Erect cowpea was grown by 38% of the interviewed households. The erect type seemed to be cultivated less by the 'poorer' households, as only one of both Farm Types 1 and 2 cultivated it (Table 18). Local cowpea was, except for one farmer of Type 4, used for own consumption only. The erect cowpea was sold by 4 of the 9 households, all belonging to Farm Types 4 and 5.

Also in Bundunia, farmers' estimated final grain yields of both types of cowpea were low: 401 kg ha^{-1} for the erect type and 74 kg ha^{-1} for the local type. From the local type however, also leaves and fresh grains were harvested for direct consumption. Yields may nevertheless be important, as early harvests come at a time of food scarcity. Leaves of erect cowpea were not eaten as they were mostly treated with insecticides.

Cowpea was mostly cultivated on medium to fertile soils, with no differences between the local and erect types. This was unexpected as manure was often applied to the mixed cowpea-millet fields close to the house which were therefore expected to be more fertile. 15 out of the 25 fields with local cowpea received manure. On eight fields mineral fertilizer was applied, all receiving NPK (15-15-15) and six also sulphate of ammonia. Fertilizers were targeted to the millet or maize, which was intercropped with the local cowpea. None of the erect cowpea fields received manure, while three of the eight fields received some NPK (15-15-15). Local cowpea residues were most often used as fodder, whereas for erect cowpea, half of the farmers left them in the field and the other half used it as fodder (Table 19).

While all erect cowpea fields were treated with insecticide, none of the local cowpea fields were treated. One of the interviewed farmers was part of the N2Africa project last year and received Cyperdicot (Dimethoate 250 mg/litre and Cypermethrin 30 mg/litre) which he also used to spray fields of other farmers. Farmers who did not receive Cyperdicot through the project, used Lambda-cyhalothrin. On average fields were sprayed 4 times. Fields of farmers who received pesticide through the N2Africa project, were sprayed 5 times. Also in Bundunia, none of the households applied insecticide on the local cowpea type. Both the erect and the local cowpea type were given a pest score of 2.

Cowpea and it is possibilities for relay cropping

Current cowpea cultivation in Kpatarr Bogu

Erect cowpea was appreciated for its good taste and commercial value. The local type was liked because it could produce without spraying insecticide, whereas for the erect type insecticides are needed.

Overall the area cultivated with cowpea (both types) stayed the same or slightly decreased in the past 3 years (Table 20). Reasons named for decreasing the area were difficulties in cropping cowpea and lack of funds. Some farmers mentioned; 'erect cowpea is the last crop to be sown, often we have run out of money for ploughing by then or need the available money for fertilizer or weeding.' Good returns was the most important reason for increasing the cultivated area of erect cowpea.

Table 20. Percentage of interviewed households who said that their cultivated area of cowpea (both types) increased, decreased or stayed the same over the past 3 years

	Kpatarr Bogu (n=30)	Bundunia (n=26)
Increased	29	32
Decreased	36	12
No change	36	56

Lack of funds for ploughing or insecticides were the most important constraints mentioned by farmers not cultivating erect cowpea. This reason was mentioned by half of the farmers, while land or labour shortage was only mentioned 1 and 2 times respectively.

Current cowpea cultivation in Bundunia

Most important reason to cultivate erect cowpea was its higher (grain) yield and its better profitability than local cowpea. Local cowpea was appreciated for the use of its leaves. Another reason recalled for both types was that it is 'good for the blood' or 'it helps the body'.

Overall the area cultivated for both types slightly increased (Table 20). Important reasons were its good returns and the availability of funds for ploughing the additional area. Some people mentioned stray animals disturbing the cowpea and therefore decreased the cultivated area.

Most important constraints for people not to cultivate erect cowpea, or not increasing the area cultivated, were labour shortage at time of harvesting and shortage of funds for insecticide. Other constraints mentioned were the lack of money for ploughing and land shortage. Almost all farmers mentioned at least once the lack of capital for crop production

Farmers opinions on early cropping of erect cowpea

In Kpatarr Bogu opinions were divided on whether early cowpea planting after the first rains in early May was possible or not (Table 21). Some mentioned that it would only be possible if cultivated on loamy soils for it has a good water holding capacity. Negative answers were related to periods of dry spells early in the season and high temperature early in the season. It was also mentioned that the heavy rains would coincide with maturity, causing the pods to rot.

Table 21. Opinions on cultivating erect cowpea after the first rains as an early crop (percentages of households).

	Kpatarr Bogu (n=30)	Bundunia (n=26)
Possible	47	10
Impossible	47	43
No opinion	7	33

In Bundunia there was one, woman-headed, household who planted erect cowpea directly after the first rains. It was the first time cultivating erect cowpea for her and she said: 'In this part of the year we only have rice, nothing else, therefore I wanted to try planting cowpea early'. The majority of the interviewed households thought it to be impossible to sow cowpea at the onset of the rainy season (Table 21). The reason most often mentioned for this was that flowering and podding would then coincide with heavy rains in August, causing flowers to drop and pods to become mouldy. Another reason was the shortage of labour for harvesting at that point in the season. Both reasons were partly related, as one farmer said, 'if you would have enough people you could pick directly when a pod is mature and nothing is spoiled, even if it rains'.

Farmers opinion on relay cropping of maize into early cowpea
After explaining the cropping system tested in the experiment, people were asked about their opinion on possible advantages and constraints for this system. Similar answers were grouped and then ranked to determine most common advantages and constraints mentioned for cowpea-maize relay cropping (Table 22).

In Kpatarr Bogu mostly prerequisites for the relay cropping were mentioned, instead of advantages. Leaving enough space for the maize when planting the cowpea was most often mentioned. Giving enough fertilizers to both crops in order to let them both grow well, was another prerequisite often mentioned. A bigger number of constraints was mentioned than the number of advantages. Constraints most often mentioned were: the expectation that maize growth would be affected by the cowpea due to shading or vines and the occurrence of dry spells and heat early in the season. One farmer in Kpatarr Bogu said that he saw no reason for relay cropping, he had enough land, so why not separate the two crops.

Also in Bundunia more constraints were mentioned than advantages. The two advantages that were expected were early food production and a higher total yield. Important constraints mentioned were: the expectation that maturity would coincide with the heavy rains, that maize growth would be affected by the cowpea and the expected need for extra labour. The need for extra labour was mentioned by three 'better-off' farmers. One of them said, 'harvesting cannot be done fast-fast' and applying insecticide to the cowpea is more difficult.

Table 22. Advantages and constraints for cowpea-maize relay cropping as mentioned by the interviewed households grouped per topic and ranked from most recalled constraint to least recalled constraint. In Kpatarr Bogu 30 households were interviewed and in Bundunia 26.

Kpatarr Bogu				Bundunia			
Advantages		Constraints		Advantages		Constraints	
Kind	#	Kind	#	Kind	#	Kind	#
Only with right spacing	7	Maize growth affected	12	Early food	4	Maturity coincides with heavy rains	7
Only with sufficient fertilizer	5	Drought or heat stress (cowpea)	8	More yield	3	Maize growth affected	4
More yield	3	Cowpea growth affected	4			Extra labour needed	4
Early food	1	Maturity coincides with heavy rains	3			Cowpea growth affected	2
Cowpea good for soil fertility	1	Extra labour needed	2				
Total	17		29		7		17

When continuing the discussion on opportunities for cowpea-maize relay cropping, it often became clear that erect cowpea was commonly seen as a commercial crop that one would harvest for dry grains only, all at once and sell part of it. Bringing up the possibility of cropping only a small area, for fresh (home) consumption, leaving indeed space for the maize to emerge and grow, mostly gave positive responses in both villages. Or they thought that, at least it should be tested. However, even for a smaller area inputs as insecticide and a knapsack sprayer would be needed for spraying, which was mentioned as a possible problem for the poorer farmers.

Availability of short duration maize

In both Kpatarr Bogu and Bundunia the most popular maize variety was Obatanpa, cultivated by almost all interviewed households. Obatanpa is an open-pollinating 105 day variety that was introduced in 1992 and bred for its good yield and high protein content (Badu-Apraku et al. 2006). The second most common variety was yellow or red maize which was said to be a local variety, maturing in about 90 days. In Bundunia 7 farmers also mentioned Dorke SR as an early maturing variety that they knew, 2 of them also cultivated it. Early-millet was also mentioned as an early maturing cereal (2.5 months) and cultivated by 65% of the households in Bundunia.

In both places there were therefore different short duration cereals that could fit in a cowpea-cereal relay cropping system. However, for yellow maize and short duration millet, yield potential is unknown.

Discussion

Soil fertility

Anticipated differences in soil fertility between trial fields were not in line with the results from soil analyses, interviews and the historical yields derived from these interviews. In Kpatarr Bogu only the selected low fertility field showed a considerable lower fertility than the high and medium fertility fields, whereas there were no considerable differences in fertility between the high and medium fertility fields. In Bundunia this was the case for the low and medium fertility fields, for which there were no considerable differences in fertility and only the high fertility field was found to be more fertile. This was reflected in cowpea grain yields, which were only significantly different for those fields which were also considerable different in soil fertility. The high and medium fertility fields had a 30% higher grain yield than the low fertility field in Kpatarr Bogu, the high fertility field in Bundunia had a 60% higher grain yield than the low and medium fertility fields.

Total biomass yield at mid-pod filling showed no significant differences between fertility levels. Total biomass yield at maturity (final harvest) was only significantly affected by fertility levels at Kpatarr Bogu (lower for the low fertility field than the medium and high fertility field), and not at Bundunia. When considering stover and grain yield separately, only grain yield for part of the fertility levels was significantly different, in both places (and stover yield not). Average cowpea grain yields for the different fertility levels ranged from 0.57-0.76 Mg ha^{-1} in Kpatarr Bogu and 0.7-1.21 Mg ha^{-1} Bundunia.

Ojiem et al. (2007) and Ojiem et al. (2014) also showed different grain yields of grain legumes for different fertility levels. It is however unknown if they also found no differences in maximum biomass or stover yield for different fertility levels. Carsky et al. (2001) found three year average grain yields of 0.46 and 0.77 Mg ha^{-1} in sites selected for low and high P availability respectively with short duration cowpea varieties (corrected for 12% moisture). Trials were conducted on a similar latitude, in northern Nigeria with sole crop cowpea (±140000 plants ha^{-1}) and no insecticide application. Grain yields were comparable with this research, although their low-P site yield gave a lower grain yield than in this research. Their plating density was almost three times as high as in this research, no insecticide application might however be the reason for similar yields.

Historical yields were based on farmer estimated total yield and field size, especially for smaller farms and fields this can result in considerable errors (Carletto et al. 2011). Historical yields were most probably also influenced by management and not only field fertility. A rapid soil sample analysis before planting could also have helped to estimate soil fertility more reliably. Due to time constraints this was however not possible.

The quality of the soil sample analysis by the soil laboratory is not known. The results of soil sample analysis corresponded however well with the historical yields and the results of both harvests. Comparing the results of soil sample analysis with the range of common values found in both regions shows that N concentration in Kpatarr Bogu was higher in trial fields than the average in the region, whereas for Bundunia this was the opposite, with lower values than common (Table 23). Although interviews indicated that fertilizer use in Bundunia was more common than in Kpatarr Bogu, OC and N concentration were still lower in Bundunia. This can be partly explained by the differences in particle distribution, with higher percentage of sand and lower percentages of silt and clay in Bundunia than in Kpatarr Bogu (Giller et al. 1997). P-Bray values were comparable and within the ranges for both locations. Only the medium fertility field in Bundunia gave a more favourable value.

Comparing the soil sample analyses values with critical values for agricultural production as described by Fairhurst (ed. 2012) showed that OC, total N, available P, CEC, sand and clay percentages (for both locations) and K (in Bundunia) were critically low. This will most probably result in N, P and K deficiencies, poor nutrient retention, low indigenous N supply and high risks of leaching losses (Fairhurst (ed.) 2012). The so-called high, medium and low fertility fields should

Table 23. Critical values for soil fertility parameters and common values found for this within the Northern and Upper East region of Northern Ghana.

	pH 1:1 H_2O	OC (%) Walkley & Black	N (%) Kjeldahl	P (mg/kg) Bray	K (cmol/kg) Ammonium Acetate	Ca (cmol/kg)	Mg (cmol/kg)	CEC (cmol/kg)	Sand (%)	Clay (%)
Critical values[1]	<4.5	<1.5	<0.15	<15[2]	<0.2	<0.5	<0.2	<10	>50	<30, >45
Common values Northern Region	4.5-6.7	0.6-2.0	0.02-0.05	2.5-10.0[3]		0.11-0.22				
Common values Upper East Region	5.1-6.8	1.1-2.5	0.06-0.14	1.8-14.8[3]		0.11-0.38				

[1] Critical values obtained from Fairhurst (ed.) (2012). Values common in the Northern and Upper East Region from MoFA (2012)
[2] Bray II method
[3] Bray I method

therefore be seen on a relative scale, all having low soil fertility. This pattern is often observed in agricultural fields in SSA. Ojiem et al. (2007) for example also described low overall soil fertility in similar trials using a fertility gradient in Kenia. Ranges of common values for N, P and Ca in the Northern and Upper East Regions were below the critical values, showing that agricultural fields in northern Ghana are generally poor in soil fertility.

Weather conditions

The observed differences in rainfall between the two AEZs selected in this work were unexpected. While Kpatarr Bogu was expected to receive similar or more rain and have a longer growing season, actual rainfall in Kpatarr Bogu was less and more erratic than in Bundunia. It seemed that cowpea growth was more constrained by dry spells in Kpatarr Bogu than in Bundunia. The unusual rainfall pattern in Kpatarr Bogu this season probably caused the lower cowpea yields in Kpatarr Bogu than in Bundunia. It probably also affected planting arrangements, which is discussed in the following section.

Seasonal differences also affected the moment of sowing. Although farmers in Kpatarr Bogu planted their early crops around the normal time, the main crops were planted one month later than mentioned in the cropping calendar (Table 17). Cowpea in the experiment was sown just before farmers planted their main crops, thus not as one of the early crops. In Bundunia, cowpea in the experiment was sown at the same time when farmers were sowing their early crops. This would normally be more than one month earlier (Table 17). If the cowpea in Kpatarr Bogu would have been sown together with the early crops it would probably have experienced even more dry spells, as it took long for the rains to establish in 2013.

Variation in yield

The relatively high total biomass yield and low harvest index of cowpea at final harvest in the medium fertility field in Bundunia was probably because of the re-sown cowpea in this field, which received more stable rains. Maize plants in the low and medium fertility fields in Bundunia were also affected by stray animals, overriding effects of maize on cowpea growth.

All yield data showed considerable variation within treatments. As Annex II showed, all fields had within field variability, some caused by management (i.e. ploughing gullies), others being part of the field (e.g. trees, stony patches, a former charcoal-making area). Variations in yields could not be related to this within field variability. This is in line with Tittonell et al. (2005b), who found that within field variation in farmers' fields, especially in SSA can be very high. Therefore (timely) field selection and experimental design is very important.

Planting arrangements

Planting arrangements did not significantly affect yields. Dry spells in Kpatarr Bogu and low maize germination in Bundunia resulted in no or little impact of planting arrangements on cowpea growth.

Apart from dry spells, differences in management practices between the two sites also affected the results. Cowpea growth in Bundunia was probably not influenced by the maize due to the low germination of cv. Dodzi in general (most probably due to low seed quality) and the field specific variations mentioned in the previous section. Re-ridging in Kpatarr Bogu most probably caused the low emergence rate of maize in the 6wk planting arrangements. Re-ridging may not be advisable at that time. Weeding was a problem in the cowpea-maize relay arrangement. During weeding at 6 WAP, the 3wk maize plantlets were still small and often covered by the cowpea plants, causing many maize plants to be damaged or uprooted. In farmers' fields this risk of damaging plantlets might even be higher since labourers were paid per acre, working as fast as possible.

Other studies showed that planting arrangements affect yield in cowpea-maize systems. Mucheru-Muna et al. (2010) showed for intercropping of cowpea and maize in 1×1 and 2×2 row arrangements, significantly better yields with the 2×2 arrangements. With intercropping however, both crops are together in the field for the whole growth period, this can cause larger differences in crop growth than with relay cropping, where there is interaction for only part of the growth cycle of both crops.

Considering the whole cowpea-maize relay system, time of planting maize is likely to affect maize yield. Since cowpea yields were not affected by planting arrangements, differences in total yield of cowpea-maize relay cropping systems depended on differences in maize yields. Kamara et al. (2011) found for relay cropping of late cowpea into a maize crop, that yields of cowpea changed more than that of maize when time of relay planting into maize was altered. Differences in yields of this late cowpea crop were caused by late season dry spells.

Since both rainfall (Annex V) and seed quality can vary in northern Ghana, planting arrangements as tested in this research might not be an important factor for farmers. Planting arrangements might however still be important if this affects the ability of maize to complete its growing cycle due to late season dry spells.

Interaction between soil fertility, AEZ and planting arrangements

Only total biomass at mid-pod filling harvest in Kpatarr Bogu showed significant interaction between soil fertility and planting arrangements, which is an unexpected result. The significance mainly depended on low values for the 6wk1×1 treatment that could not be explained by observed irregularities. No similar interaction was found at final harvest. The significant interaction in maximum biomass in Kpatarr Bogu may therefore be an artefact, due to within field variability or mistakes in harvest procedures.

The lack of interaction between soil fertility and planting arrangements was probably due to the fact that planting arrangements showed no differences in yield and to large variation in yields between the replicates. From this research no preferred planting arrangements could be identified for different soil fertility levels or AEZ.

Nodulation

Average number of nodules per plant showed only significant differences between Kpatarr Bogu, and Bundunia and not between fertility levels. Soils in Kpatarr Bogu were less sandy, contained more organic matter and rotations with legumes were found to be more common, all factors that may have increased the numbers of rhizobia in the soil (Giller 2001). This can have resulted in better nodulation in Kpatarr Bogu. The differences in occurrence of legume rotations and in soil parameters were much bigger between Kpatarr Bogu and Bundunia than between the fertility levels. This can be the reason why differences in fertility levels did not result in differences in average number of nodules.

Percentage of active nodules was also lower in Bundunia than in Kpatarr Bogu, supporting the idea that soil conditions were more favourable for N_2-fixation in Kpatarr Bogu than in Bundunia. Active nodules refer to nodules that are active at the moment of observation. Nodules that were for instance green inside were considered inactive. They were active previously, and are senescing when green (Giller 2001). Therefore the percentage of active nodules per plant is not necessarily related to total N-fixed, but rather an indication for N_2-fixation at the moment of observation.

Although active nodules in Kpatarr Bogu gave significant interaction between fertility level and planting arrangement, the variances between the treatments were not equally distributed (Bartlett's test for homogeneity). With no consistent pattern in the differences, it is difficult to explain the results. Activity of nodules, like number of nodules per plant, generally shows high variability (Giller, personal communication 2013), which might be one of the causes.

Better nodulation however, was neither reflected in higher total biomass yield, at mid-pod filling harvest, nor at final harvest. On the contrary, biomass and grain yields were higher in Bundunia than in Kpatarr Bogu. As was earlier described, this was most probably due to dry spells in Kpatarr Bogu.

Nitrogen budgets

Values found from literature for N-concentration of grains and percentage of N-fixed through N_2-fixation were similar as found by Ronner and Franke (2012). They found a somewhat higher average N-concentration of stover, 3.1% instead of 2.5%, which can be due to the lower number of sources used in their study. The average and range for N-concentration of grains and percentage of N-fixed found in this study was also comparable with those found by others (Giller 2001).

Mid-pod filling stage was assumed to be the moment of peak total above ground biomass. Total biomass yield at final harvest (maturity) was however often higher than at mid-pod filling stage. It proved to be difficult to determine peak total above ground biomass based on physiological stage. The highest measured total above ground biomass, either at mid-pod filling stage or maturity, was used to calculate total above ground N.

Partial N-budgets showed that when using 'best practices' (from the perspective of soil fertility, scenarios 3 and 4) the cowpea crop gave positive budgets, even if the lowest values found for %N from N_2-fixation were used. Taking all above ground parts out of the field (Scenario 2) resulted in slightly positive budgets. Scenario 2 would however result in negative budgets for all fields if the lowest values for %N from N_2-fixation are used. Not taking into account belowground biomass in calculating N-budgets always resulted in negative contributions to soil N, even if highest values found for %N from N_2-fixation were used.

The high fertility fields gave higher N-budgets than the low fertility fields. Also others found N-contributions of legumes in high fertility fields to be higher than in low fertility fields (Ojiem et al. 2007). Differences in N-budgets between soil fertility levels in this study seemed solely determined by the effect of soil fertility level on grain yield. Cowpea grain yield was significantly affected by fertility level, whereas stover yield was not.

%N derived through N_2-fixation is positively influenced by soil fertility level (Ojiem et al. 2007), while not necessarily influencing biomass accumulation at the same rate (Muchow et al. 1993). Differences in N-budgets between the fertility levels can therefore be larger than calculated here, as differences in N_2-fixation rate for different fertility levels were not taken into account. In East-Africa soil fertility was related to wealth and resource endowments (Tittonell et al. 2009; Tittonell et al. 2005a). If this is the same in northern Ghana, this would mean that 'poorer' farmers, who generally have fields that have lower soil fertility, have less incentives to use good practices to improve soil fertility since they will see less effects of these good practices.

The N-budgets of Adjei-Nsiah et al. (2008) for a different variety of cowpea, in central Ghana, were calculated in the same way as was done in Scenario 3. They found values ranging between 19 and 60 kg N ha^{-1} when including belowground-N, which was higher than the range found in this research, 16 to 33 kg N ha^{-1}. Differences could be explained by the more favourable climate (1350 mm annual rainfall in their study) and also because they grew cowpea as a sole crop, resulting in higher grain yields for example (1.1-1.4 Mg ha^{-1}).

Contributions of N to the succeeding crop might however still be marginal. The highest N-budget in this research resulted in a net contribution of 33 kg N ha^{-1}. Giller and Cadisch (1995) described that only 10-20% would be available for a subsequent crop in the following season. Nitrogen contributions of the cowpea crop to the subsequent maize crop, even in scenarios 3 and 4, might therefore only be 6 kg N ha^{-1}. Recommended N-fertilizer rates of maize for northern Ghana were at least 60 kg N ha^{-1} (Fosu et al. 2012). The sparing effect, i.e. that the cowpea crop doesn't take N which can then still be available to the subsequent (maize) crop, might therefore be more important (Giller 2001).

Applicability of the N-budgets

Scenario 3 was found to be most applicable to Kpatarr Bogu where residues were left in the field (Table 11). Two out of the five farmers who cultivated cowpea did however say they had applied manure to their field, but as no residues of this fields were used as fodder, Scenario 4 did not fit here. In Bundunia about half the households that cultivated erect cowpea used it as fodder. Among those households, none applied manure to one of these fields. Manure was only applied to the mixed millet and local cowpea fields, not to erect cowpea. This implies that for the erect cowpea, scenarios 2 and 3 were representing the cropping system in Bundunia best.

Scenario 4 was not representative for any of the interviewed households. It was however still shown, as crop-livestock integration could be considered as a plausible option for improved fertility management in which probably least amount of N is lost and turnover rates of nutrients are highest, which might lead to a higher production (Franke et al. 2010). In Kpatarr Bogu farmers mentioned the risk of poisoning their livestock as erect cowpea needed insecticide application. Advise on the use of the right insecticide, at the right time (not in the last two weeks before harvest) could help in avoiding risks of poisoning.

Possible beneficial effects on the N-budget of a field from a legume crop are often not considered as the most important benefit by farmers. Financial benefits, for example, are seen as more important (Giller and Cadisch 1995; Schlecht et al. 2006). These are discussed in the following section.

Financial benefits

The relay cowpea crop was estimated to be profitable in both scenarios and all fertility levels (Table 13). Even considered as a sole crop, its BC ratio was still around 1.5. When considered as a component of the cropping system, its BC ratio was close to 2. A BC ratio of 2 is often considered a threshold value for uptake by smallholder farmers (Ebanyat et al. 2010). Relay cropping with maize probably made cowpea less profitable than sole cowpea cropping, since the planting density in the experiment was only around 1/2 or 1/3 of the recommend density for sole cowpea. An assessment of the profitability of the entire cowpea-maize cropping system is needed to evaluate the potential uptake of this new technique. The maize component would strongly influence this, not only in monetary value, but also in farmers preference. As maize is an important staple crop in northern Ghana, it is seen by farmers as more important than the legume component. This is for example one of the reasons why in Malawi 'poorer' farmers or those with small landholdings often have a bigger proportion of their land cropped with maize than better resource endowed farmers (Kamanga et al.

2010; Van den Brand 2011). The effect of this cowpea-maize relay cropping on the maize crop will therefore mostly determine the success of the system, especially for the low resource endowed farm types.

The lower profits and BC ratios for the low fertility fields in comparison with the high fertility fields reflected the N-budgets. Also in literature it is often found that fields higher in fertility level give more favourable BC ratio's than low fertility fields. Therefore there is a higher incentive for farmers to use soil fertility measures in fields that have already a better soil fertility (Ebanyat et al. 2010; Ojiem et al. 2014; Tittonell and Giller 2013). This phenomena can lead to fertility gradients between fields, whereby it becomes less and less interesting to invest in low fertility fields (Tittonell et al. 2007). If food demands increase as predicted, such low fertility fields will be needed for production. More drastic measures (i.e. fertilizer subsidies, organic matter transfer) than cowpea-maize relay cropping might be needed to keep or make production viable in these low fertility fields (Pretty et al. 2011; Tittonell and Giller 2013; Vanlauwe et al. 2010).

Current cropping system

From the perspective of SAI, the agronomic and economic benefits of a new technique are important, but these should fit within an existing farming systems. The information from the interviews and the development of farm typologies based on these gave an insight into this existing system.

Kpatarr Bogu showed a more diversified cropping system than Bundunia, in sowing time and in number of crops cultivated. In both places, erect cowpea was the third most popular legume after groundnut (both places), soya bean (Kpatarr Bogu) and local cowpea (Bundunia). The longer rainy season allowed a more diversified cropping pattern in Kpatarr Bogu. Farmers seemed to spread the risk of crop failure due to dry spells by planting at different dates and were also able to plant more water demanding crops like yam and cassava.

The different organisation and outlays of the farms indicated however that there also were other local differences that influence the cropping system. Bundunia seemed to have more opportunities for generating off-farm income than Kpatarr Bogu. The rice irrigation scheme and governmental institutes gave opportunities for off-farm income in Bundunia, which could for example be invested in fertilizer or livestock. Fertilizer use might also be more needed in Bundunia than in Kpatarr Bogu as land holdings were smaller. Even though estimated landholdings might not be very trustworthy (Carletto et al. 2011), the estimated differences were considerable. The smaller land holdings in Bundunia can also be related to population density which is 21 and 92 people km^{-2} for Kpatarr Bogu and Bundunia respectively (UNDP 2010a; 2010b).

In Kpatarr Bogu, alternative opportunities for off-farm income generation were scarce and main regional markets were nearby, which can be reasons for the focus on trading and selling of local produce in this village. This could also be one of the reasons why soya bean was such a popular crop in Kpatarr Bogu.

Farm typologies were based on factors which are commonly used to describe farm types (resource endowment, sources of income and land holding). More detailed farm characterizations often also include other factors like age and education of the household head and production orientation (Alvarez et al. 2014; Giller et al. 2011; Tittonell et al. 2010). This research therefore gave an indication of what kind of farm types are present and how this could affect cowpea cultivation. It aimed to cover all farm types, including the richest and the poorest. Specific targeting of these groups made that the number of households per farm type are not representative for the distribution of these farm types within the communities. Characteristics that were most important to determine different farm types reflected however the different socio-economic conditions of the two locations. For instance in cattle owned and fertilizer use, which were both more prevalent in Bundunia than in Kpatarr Bogu.

Opportunities and constraints for cowpea-maize relay cropping

Farmer estimated yields for erect cowpea were three to five times as high than those of local cowpea. This difference might be partly explained by the fact that local cowpea was always part of an intercropping system, whereas erect cowpea was only grown as sole crop. Erect, improved cowpea however, also often has a potential for higher yields than local cowpea (Ehlers and Hall 1997; Singh 2006), which most probably also explains part of this yield difference. Promoting erect cowpea in the research area might therefore lead to higher cowpea yields if this replaces local cowpea. Promoting improved management strategies could possibly further increase yields. Cowpea yields found in the experiment (relay crop) were 1.5 to 2.5 times higher than farmer estimated yields for erect cowpea (sole crop), indicating another important part of the yield gap.

The need for pest control in erect cowpea (and its subsequent cost) seemed to be the most important constraint to cultivate erect cowpea. In Kpatarr Bogu for example, soya bean was often recalled as more favourable as it did not necessarily need pest control to obtain produce. Another reason not to cultivate erect cowpea was the late advised (by MoFA) sowing time. Funds available for land preparation were already spent at the time of cowpea sowing. This can be a reason why erect cowpea was cultivated more by 'better-off' farmers and less by 'poorer' households. All households that cultivated erect cowpea also sold part of their produce, while local cowpea was mostly used for home consumption. Erect cowpea seemed to be merely seen as a more commercial crop, cultivated by the more wealthy farmers, late in the season. Something that was for example also found by Van den Brand (2011) for other legumes in Malawi. Kamanga et al. (2010) described how this might be caused by riskiness, which was higher for 'poorer' farmers, mainly due to their generally lower yields. The earlier discussed generally more fertile fields and related higher yields for 'better-off' farmers, can also in northern Ghana make it more attractable for 'better-off' farmers than for the 'poorer' to adopt cowpea-maize relay cropping. Furthermore, 'better-off' farmers might find it easier to start using this cropping system as they might take more risks (of earlier planting) and because cowpea seems to be already cultivated most by this group of farmers. They have thus the materials like seed, knapsack sprayer and insecticides that makes it relatively more easy for them to try cowpea-maize relay cropping. The 'poorer' are therefore estimated to have less benefits from this technique, which could lead to lower adoption rates.

Early food availability through early cowpea cultivation would however especially benefit the 'poorer' households in terms of food provision, as they had biggest food shortages at that time of the year. In Kpatarr Bogu early cowpea could provide food during the peak of food shortage, while in Bundunia this could be towards the end of the food gap. In Bundunia other measures than cowpea-maize relay cropping should be considered to 'fill' the whole period of food shortage. The main advantage of early cowpea in Kpatarr Bogu would be that it could be harvested at least one month earlier than groundnut, which is now often used as an early food crop. In Bundunia no early legumes were grown and only early millet would be ready around the time of early cowpea harvest. In both villages the nutritional benefits of cowpea were appreciated, providing an additional reason to cultivate erect cowpea early. Since the introduction of an early cowpea relay crop in northern Ghana would result in having more spread out planting and harvesting dates, it can help to spread the risks of dry spells and therefore contribute to a more resilient cropping system.

Cultivating erect cowpea early, for own food production, on a small acreage was not practiced and a new idea to the interviewed households. Explaining this practice and the objective of own, early food provision often resulted in more positive responses as, 'yes that is something we could try' or 'could you show me how you do it'.

Constraints for cowpea-maize relay cropping seemed to be prevailing over the opportunities that were mentioned. Only with a wide spacing of the cowpea, the relay cropping was seen as feasible, which was linked to the most frequently mentioned constraint that maize growth would be affected by cowpea. Considering the generally low planting densities observed, cowpea would then be more a bonus crop, resulting in a lower profitability than found in this research. Therefore, not only the introduction of the tested cowpea-maize relay cropping combination might be needed. To increase the possible adoption, there should also be a strong focus on improving current crop management (i.e. fertilizer application, residue management, spacing, insecticide application). Cowpea-maize relay cropping seemed thus 'far' from farmers practices and their opinion on how and when cowpea should be cultivated. This is often seen as an important constraint for uptake of new techniques.

Results, however, showed that early relay cowpea can be an option for SAI as it; can be a profitable crop for all soil fertility levels, can give higher yields than local cowpea, can contribute to food availability in a lean part of the season and contribute to soil fertility if promoted in combination with mineral fertilizer application and best practices in residue management. Dissemination trials for example might be a way to promote this new cropping method in northern Ghana and a way to overcome the constraint of being 'far' from current farming practices. These trials could also be used to further research and understand the dynamics around cowpea-maize relay cropping within the paradigm of SAI.

Conclusions

- Cowpea grain yields were found to be significantly higher for higher fertility fields than for lower fertility fields in both Kpatarr Bogu and Bundunia.

- The variable climate in both regions and the low quality maize seeds that were used in Bundunia, might have been the reason why planting arrangements showed no effect on yield variables. From this study it can therefore not be concluded whether there is an optimal planting arrangement for cowpea in cowpea-maize relay cropping and whether this differs for different fertility levels or different AEZs in northern Ghana. Planting arrangements can however affect maize yields, which can therefore still result in optimal cowpea-maize relay planting arrangements. The maize crop was however not taken into account in this study.

- The cowpea crop in cowpea-maize relay cropping was found to be profitable for all fertility levels, also if considered as a sole crop (accounting all cost, like land preparation, for cowpea). Cowpea yields in the trials (relay cropping) were found to be 1.5-2.5 times higher than farmer estimated current yields (sole crop), which indicates a potential for better cowpea yields, possibly through better crop management (i.e. fertilizer application, timely weeding, correct spacing).

- N_2-fixation of early cowpea in cowpea-maize relay cropping was found to result in moderate positive N contributions of the cowpea crop.

- If early cowpea in cowpea-maize relay cropping is planted at the onset of the rains, it can produce more nutritious food in a period of the season when otherwise there is food shortage (food gap). This food gap was found to be biggest for the 'poorer' households.

- Benefits of the cowpea crop (financial and N-contributions) were more favourable for the higher fertility fields and less for lower fertility fields, resulting less in incentives to use this method for sustainable intensification on low fertility fields. Other measures than promoting cowpea-maize relay cropping can therefore be needed for SAI in these poorer fields.

- 'Better-off' farmers might find it easier to start using cowpea-maize relay cropping as they tend to have the more fertile fields, they can easier take the risk of earlier planting and because erect cowpea seems to be already cultivated most by this group of farmers. The 'poorer' are therefore estimated to find it harder to adopt this technique as they have less benefits from this technique.

- Since early cowpea relay cropping is not closely related to current practices of all interviewed households, dissemination trials (or similar demonstrations) can be an option to promote this technology. If cowpea-maize relay cropping is to be targeted to the 'poorer' households, special measures for this group might be needed (i.e. supplying or subsidising sprayers, insecticides or mineral fertilizers).

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Annex I – Field history survey

Field history survey

Name of the interviewer:________________________________

Date of interview: _____/______/2013

District: ___________________

Village: ______________________

GPS coordinates of trail field (decimal degrees) North/South:____________________
East/West: _______________________ Altitude: ___________________(meter)

Part A: General information

A.1. Name of the farmer: ____________________________

A.2. Sex of farmer: Male ___ /Female ___ Age: _____

A.3. Is farmer head of the household: Yes ___ / No ___

A.4. If no, head of household is Male ___ /Female ___ and Age _____ years

A.5. Total number of people in the household:________

A.6. Total farm size: ________ha/acre

Part B: Field characteristics

B.1. Size of the field: ________

B.2. Ownership of the field: _____________

B.3. Slope: ________ (1. Flat- 5. Steep)

B.4.a Fertility level _______ (Low, Medium, High) according to farmers experience

B.4.b Fertility level _______ (Low, Medium, High) according to researcher observation

B.5 Is there any within field variability known like boulders, water logging or a fertility gradient?

*Depict particularities in the field here

Part C: Field history

C.1.

Year	2010	2011	2012
Crop(s) grown (if intercropped, mention all crops and indicate relative shares, e.g. 80% maize / 20% beans)			
If legumes were grown, were inoculants applied?			
	Type: Amount:	Type: Amount:	Type: Amount:
Organic inputs applied? If yes what?			
Total harvest from this field (give unit, e.g. in kg or 50 kg bags)			
Residue management			
Herbicides used? If yes what?			
What was the extent of insect damage, disease incidence and weed pressure?			

Do you have any questions / comments for us?

____

____

____

____

____

Thank you for your time and cooperation.

tree

Annex II – Trail outlays and observed irregularities

Treatment summary can be found below.

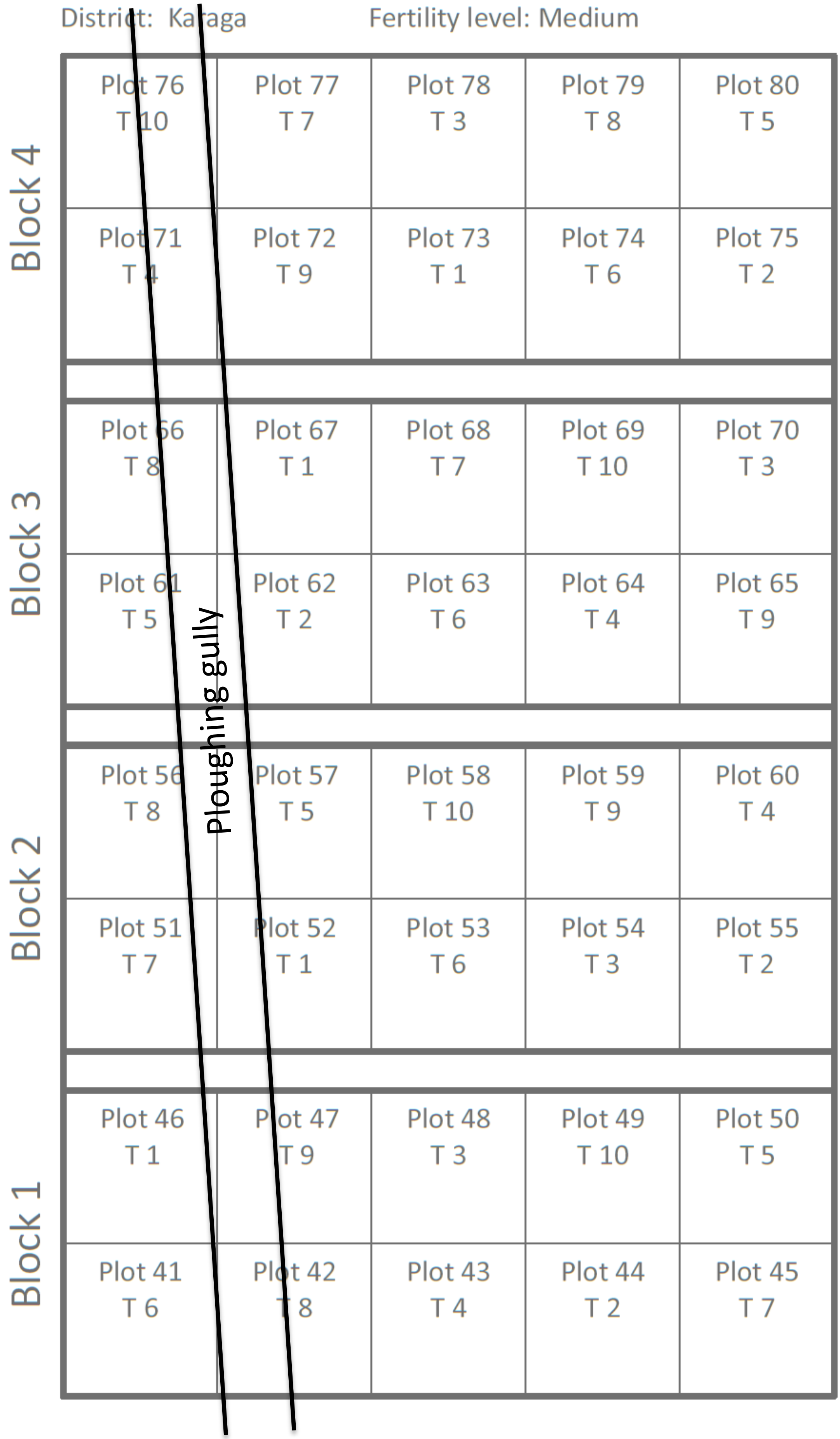
District: Karaga Fertility level: Low

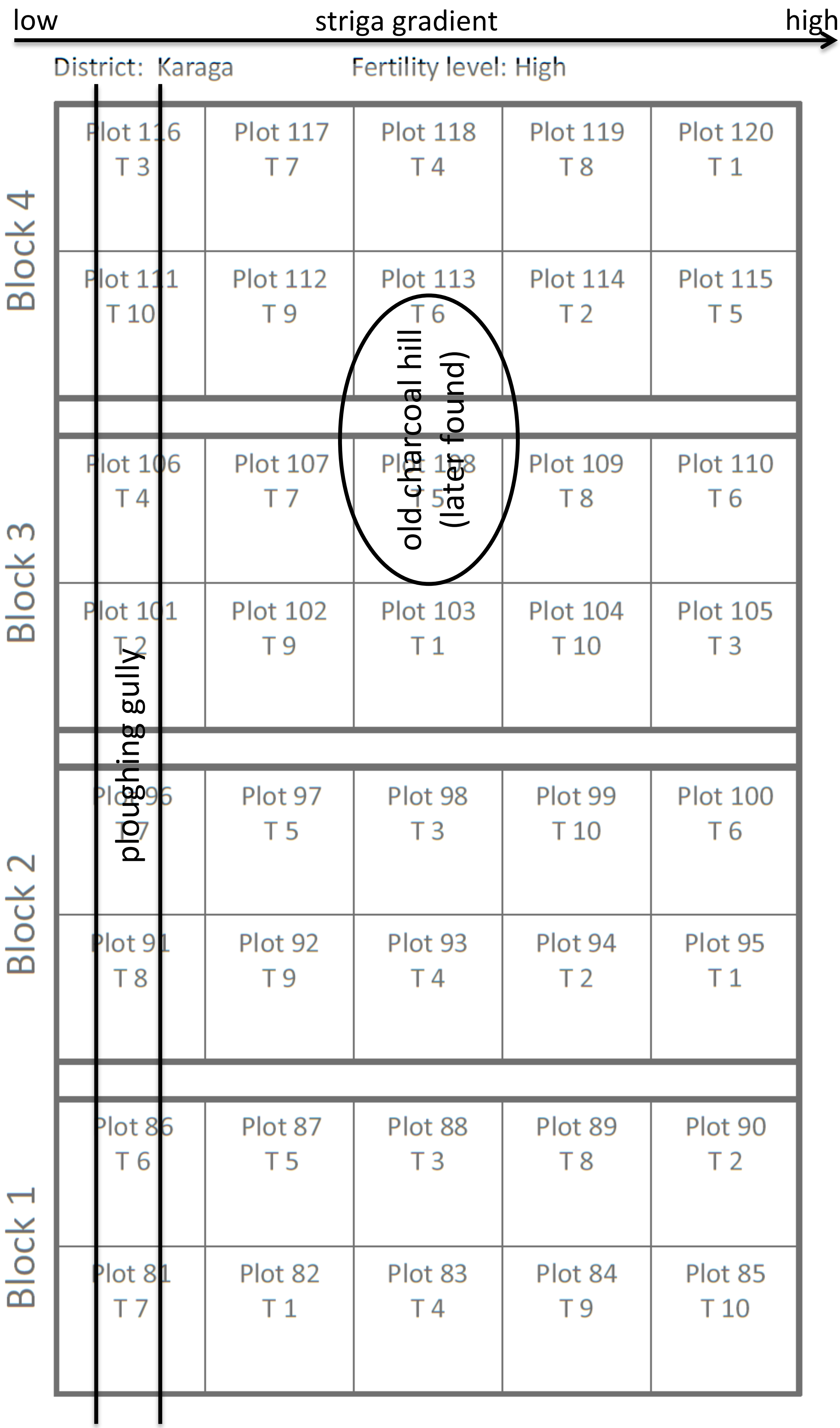
Block 4	Plot 36 T 5	Plot 37 T 2	Plot 38 T 10	Plot 39 T 1	Plot 40 T6
Block 4	Plot 31 T 9	Plot 32 T 3	Plot 33 T 7	Plot 34 T 8	Plot 35 T 4
Block 3	Plot 26 T 5	Plot 27 T 1	Plot 28 T 4	Plot 29 T 3	Plot 30 T 7
Block 3	Plot 21 T 2	Plot 22 T 10	Plot 23 T 6	Plot 24 T 9	Plot 25 T 8
Block 2	Plot 16 T 5	Plot 17 T 4	Plot 18 T 1	Plot 19 T 7	Plot 20 T 8
Block 2	Plot 11 T 10	Plot 12 T 3	Plot 13 T 6	Plot 14 T 2	Plot 15 T 9
Block 1	Plot 6 T 10	Plot 7 T 1	Plot 8 T 5	Plot 9 T 4	Plot 10 T 7
Block 1	Plot 1 T 3	Plot 2 T 2	Plot 3 T 6	Plot 4 T 8	Plot 5 T 9

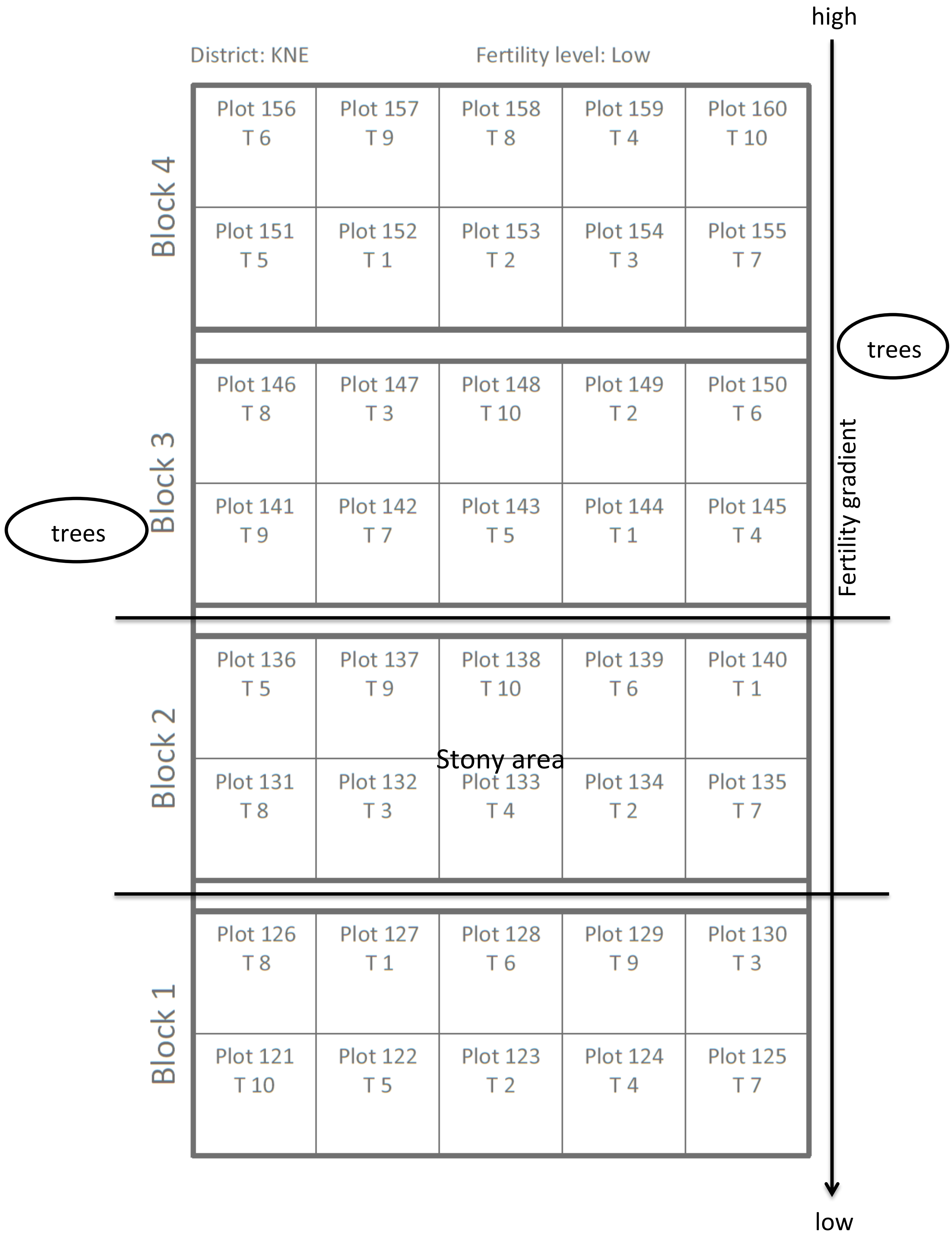
Ploughing gully

tree

District: Karaga Fertility level: Medium




low
striga gradient
high
District: Karaga
Fertility level: High
Block 4
Plot 116 T 3
Plot 117 T 7
Plot 118 T 4
Plot 119 T 8
Plot 120 T 1
Plot 111 T 10
Plot 112 T 9
Plot 113 T 6
Plot 114 T 2
Plot 115 T 5
Block 3
Plot 106 T 4
Plot 107 T 7
Plot 108 T 5
Plot 109 T 8
Plot 110 T 6
Plot 101 T 2
Plot 102 T 9
Plot 103 T 1
Plot 104 T 10
Plot 105 T 3
Block 2
Plot 96 T 7
Plot 97 T 5
Plot 98 T 3
Plot 99 T 10
Plot 100 T 6
Plot 91 T 8
Plot 92 T 9
Plot 93 T 4
Plot 94 T 2
Plot 95 T 1
Block 1
Plot 86 T 6
Plot 87 T 5
Plot 88 T 3
Plot 89 T 8
Plot 90 T 2
Plot 81 T 7
Plot 82 T 1
Plot 83 T 4
Plot 84 T 9
Plot 85 T 10
old charcoal hill
(later found)
ploughing gully


District: KNE
Fertility level: Low
high
Block 4
Plot 156 T 6
Plot 157 T 9
Plot 158 T 8
Plot 159 T 4
Plot 160 T 10
Plot 151 T 5
Plot 152 T 1
Plot 153 T 2
Plot 154 T 3
Plot 155 T 7
trees
Block 3
Plot 146 T 8
Plot 147 T 3
Plot 148 T 10
Plot 149 T 2
Plot 150 T 6
Plot 141 T 9
Plot 142 T 7
Plot 143 T 5
Plot 144 T 1
Plot 145 T 4
trees
Fertility gradient
Block 2
Plot 136 T 5
Plot 137 T 9
Plot 138 T 10
Plot 139 T 6
Plot 140 T 1
Stony area
Plot 131 T 8
Plot 132 T 3
Plot 133 T 4
Plot 134 T 2
Plot 135 T 7
Block 1
Plot 126 T 8
Plot 127 T 1
Plot 128 T 6
Plot 129 T 9
Plot 130 T 3
Plot 121 T 10
Plot 122 T 5
Plot 123 T 2
Plot 124 T 4
Plot 125 T 7
low

tree

District: KNE   Fertility level: Medium

Block 4	Plot 196 T 10	Plot 197 T 7	Plot 198 T 6	Plot 199 T 9	Plot 200 T 8
	Plot 191 T 1	Plot 192 T 2	Plot 193 T 3	Plot 194 T 4	Plot 195 T 5
Block 3	Plot 186 T 6	Plot 187 T 4	Plot 188 T 8	Plot 189 T 3	Plot 190 T 10
	Plot 181 T 7	Plot 182 T 5	Plot 183 T 1	Plot 184 T 2	Plot 185 T 9
Block 2	Plot 176 T 8	Plot 177 T 2	Plot 178 T 10	Plot 179 T 1	Plot 180 T 6
	Plot 171 T 4	Plot 172 T 9	Plot 173 T 7	Plot 174 T 5	Plot 175 T 3
Block 1	Plot 166 T 10	Plot 167 T 5	Plot 168 T 6	Plot 169 T 7	Plot 170 T 8
	Plot 161 T 1	Plot 162 T 3	Plot 163 T 4	Plot 164 T 9	Plot 165 T 2

tree

tree

District: KNE Fertility level: High

Block 4

Plot 236 T 8	Plot 237 T 5	Plot 238 T 10	Plot 239 T 7	Plot 240 T 6
Plot 231 T 2	Plot 232 T 3	Plot 233 T 4	Plot 234 T 9	Plot 235 T 1

Termite hill

Block 3

Plot 226 T 10	Plot 227 T 9	Plot 228 T 6	Plot 229 T 4	Plot 230 T 8
Plot 221 T 5	Plot 222 T 1	Plot 223 T 2	Plot 224 T 3	Plot 225 T 7

Block 2

Plot 216 T 6	Plot 217 T 3	Plot 218 T 8	Plot 219 T 2	Plot 220 T 10
Plot 211 T 9	Plot 212 T 7	Plot 213 T 5	Plot 214 T 1	Plot 215 T 4

Block 1

Plot 206 T 8	Plot 207 T 1	Plot 208 T 10	Plot 209 T 5	Plot 210 T 6
Plot 201 T 3	Plot 202 T 4	Plot 203 T 9	Plot 4 T 7	Plot 205 T 2

Annex III – Treatment structure for all treatments in the experiment

Treatment structure table for year one. Spacing between the rows for each treatment is 75 cm, within row spacing differs. Start of the cropping season depends on the start of the rainy season and therefore also differs between the two districts. As the rains were much later than expected, Dorke SR was replaced for Dodzy in KNE for treatments 1-4.

Treatment number	Crop (variety)	Time of sowing (weeks after start of season)	Spacing	Plant density (plants /ha)
1. 3wk2x2	Cowpea (Songotra) Maize (Dorke SR)	1 3	2 seeds equally spaced within row between maize planning stations 50 cm between planting stations, two seeds per planting station	53333 53333
2. 6wk2x2	Cowpea (Songotra) Maize (Dorke SR)	1 6	2 seeds equally spaced within row between maize planning stations 50 cm between planting stations, two seeds per planting station	53333 53333
3. 3wk1x1	Cowpea (Songotra) Maize (Dorke SR)	1 3	1 seed between maize planning stations, within row 25 cm between planting stations, 1 seed per planting station	53333 53333
4. 6wk1x1	Cowpea (Songotra) Maize (Dorke SR)	1 6	1 seed between maize planning stations, within row 25 cm between planting stations, 1 seed per planting station	53333 53333
5.	Maize (Dorke SR) Cowpea (Bawutawuta)	1 6	2 seed between maize planning stations, within row? 50 cm between planting stations, 2 seed per planting station?	53333 53333
6.	Maize (Dorke SR) Cowpea (Bawutawuta)	1 9	2 seed between maize planning stations, within row? 50 cm between planting stations, 2 seed per planting station?	53333 53333
7.	Groundnut (Samnut 22)	1	10 cm between planting stations, 1 seed per planting station	133333
8.	Soybean (Jenguma)	1	10 cm between planting stations, 3 seeds per planting station	400000
9.	Maize (Obatanpa)	1	25 cm between plating stations, 1 seed per planting station	53333
10.	Natural fallow	-	-	-

Annex IV – Survey

Cowpea survey

Date of interview: _____/______/2013

District: ___________________

Village: ______________________

Part A: General information

A.1. Name of the farmer: ____________________________

A.2. Sex of farmer: Male ___ /Female ___ Age: _____

A.3. Is farmer head of the household: Yes ___ / No ___

A.4. If no, head of household is Male ___ /Female ___ and Age _____ years

A.5. Total number of people in the household:________

A.6. Importance of agriculture in the household

	What are the main sources of cash income in the household? (please tick)	Please rank the main sources of income in order of importance (1 = most important, 5 least important)
Cropping		
Livestock		
Casual labour		
Trade		
Other business		
Salaried job		
Pension		
Remittances		
Other________________________		

A. 7. What are the three most valuable goods/assets in your household?

Asset type	Tick if available in the HH?	Estimated current value of asset (GHC)
Radio/sound system		
TV/DVD		
Corn mill/Rice mill		
Bicycle		
Motor bike		
Private vehicle		
Commercial vehicle		

A.8. Number of valuable livestock species owned of by the household

Cattle (no.):_________ Sheep (no.):_________ Goats (no.):__________
Pigs (no.):__________
Other valuable livestock, type: ______________________ no: _________
type: ______________________ no: _________

A.9. Do you hire labour from outside the household to work in your fields? Yes___/No____

A.10. Do you or your household members work on other people's fields for food or cash (as hired labour)? Yes___/No____

Part B: Land holding and farm management

B.1. How much arable land do you have available for crop farming (incl. fallow land)? _____ha or ____acres

B.2. Can you describe the most common crop rotation(s) on your farm?

	Crop rotation 1	Crop rotation 2
Season 1		
Season 2		
Season 3		
Season 4		

B.4. In the last cropping season, which of the following inputs did you acquire (i.e. not saved from last season)?

	Tick if obtained	If yes, please specify	If yes, specify from who you obtained it (e.g. agro-dealer, NGO, relative, government)
Legume seed			
Non-legume seed / planting material			
P-based fertiliser			
Other mineral fertiliser			
Inoculant			

Part C: Legumes

C.1. Which legumes do you cultivate on your farm? ________________________________
____

C.2. Do you use intercropping? Yes/no

If yes, which crops do you intercrop? ____
____
____

Part D: Food availability

D.1. Which crops do you cultivate? What are the important management practices and when do they take place in a normal year (not a drought year for instance)? For instance sowing (s), weeding (w), pesticide spraying (p) and harvesting (h).

	March		April		May		June		July		August		Sept.		October		Nov.	
Crop																		

D.2. In a normal year (not a drought year for instance), which months of the year do you struggle to find sufficient food to feed everyone in the household?

Tick the box(es).

	Jan	Feb	Mar	April	May	June	July	Aug	Sep	Oct	Nov	Dec
Tick the months when you struggle												

D.3. In a normal year, which months does the food consumed in the household **mainly** comes from your own farm and which months mainly from other sources?

Tick the box(es).

	Jan	Feb	Mar	April	May	June	July	Aug	Sep	Oct	Nov	Dec
Tick the months when food comes from the farm												
Tick the months when food comes from other sources												

Part E: Cowpea

E.1. Did you cultivate cowpea last year? Yes/no. If yes, fill in the table below.

Fields	1	2	3
Size of the field (acre)			
What was the field fertility compared to other fields in you farm (High, medium or low)			
Variety			
Crops grown if intercropped, mention all crops and indicate relative shares, e.g. 80% maize / 20% cowpea)			
When did you sow the cowpea?			
Fertilizers applied? If yes which type and how much?			
Organic inputs applied? If yes which type and how much?			
Total harvest from this field (give unit, e.g. in kg or 50 kg bags)			
What was done with the yield (e.g. % own consumption, stored, processed or sold)			
Residue management (e.g. sold, own use, left on the field, composted)			
Herbicides/pesticides used? If yes what?			
What was the extent of insect damage, disease incidence and weed pressure (scale non 1-5 bad)?			

E.2. What do you like about the cowpea varieties currently used?_______________________

____

____

E.3.a. In the past three years did you cultivated area of cowpea increase/decrease?

E.3.b. Could you mention a reason for this?____

____

E.4. What are the constrains for increasing the cultivated cowpea area?__________________

____

Part F. Cowpea relay cropping

F.1. Is it feasible for you to plant cowpea early in the season (after the first rains)?____

____

F.2. What are the advantage and constraints of planting cowpea after the first rains (May-June) and intercrop maize 3-6 weeks later?

Advantages____

____

Constraints: ____

____

F.3. Which maize variety(s) do you normally cultivate?

____

F.4. What other (short duration) cereal (maize, millet, sorghum) varieties do you know of that are available here?____

____

Do you have any questions / comments for us?

____

____

____

Thank you for your time and cooperation.

Annex V – Seasonal variation in rainfall

Variation in rainfall, for different months. Error bars show the standard deviation.