


The difference in food security between smallholder farmers applying **compost or mineral fertilizers** in Northern Ghana


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Abstract

Food insecurity is a serious problem in Ghana, especially in the northern regions. More than 60% of the population is dependent on their own food production. Agricultural productivity is constrained by poor soil fertility and poverty. Mineral fertilizers can boost productivity but also require a financial investment. In the last few years, two NGOs have trained smallholder farmers in Northern and Upper East regions of Ghana in the practice of composting to provide an alternative to mineral fertilizers. This study compares the food security of farmers that received training from these NGOs and apply compost to their fields with farmers that use mineral fertilizers. Farms were compared on three aspects: food production, household health and wealth. Food production was evaluated based on soil fertility, maize plant health and maize yield. Composting farmers performed significantly better for plants health and maize yield (1846kg/ha vs 1155kg/ha), but no significant differences were found for soil fertility. For the health of the household (evaluated based on adult body mass index (BMI), child BMI for age z-scores (BAZ) and child height for age z-scores (HAZ)) significant differences were found for the BAZ with a lower prevalence of underweight children among the composting group (0%) compared to the conventional group (14.9%). Wealth was evaluated based on the capital invested in different categories of animals and objects. No significant differences in wealth were found between the two farm types. The findings of this study suggest that training farmers in composting could be a promising means to improve the food security and household health of smallholder farmers.

Keywords: Northern Ghana, seasonal food insecurity, soil fertility, compost, mineral fertilizer, smallholder farmers, food production, household health

Table of contents

Terminology

Food security: "Food security [is] a situation that exists when all people, at all times, have physical, social and economic access to sufficient, safe and nutritious food that meets their dietary needs and food preferences for an active and healthy life" (FAO, 2015)
Soil fertility: "Soil fertility can be defined as the capacity of soil to provide physical, chemical and biological needs for the growth of plants for productivity, reproduction and quality, relevant to plant and soil type, land use and climatic conditions" (Abbott and Murphy, 2007).
Poverty: Condition in which people live below the poverty line , therefore living of an income that is not deemed adequate in their country.
Smallholders: Small-scale farmers with a farm area smaller than 10 hectare who are mostly dependent on their own food production (FAO, 2012).
Organic farmers: Farmers that use compost to fertilize their fields. These farmers do not use mineral fertilizers, pesticides or herbicides on their fields.
Chemical farmer: Farmers that apply mineral fertilizers to fertilize their fields. They are using (but not necessarily) pesticides or herbicides on their fields.
Maize plant health: In this study, maize pant health is determined based on physical properties. Plants that are taller, have a higher photosynthetic capacity (more and/or bigger leaves) and can produce a higher yield (more or bigger grains) are considered healthier.

BMI	Body Mass Index
BAZ	Body Mass Index for Age z-scores
HAZ	Height for Age z-scores
SEISUD	The Sirigu Ecological Initiative for Sustainable Development
ZEFP	Zasilari Ecological Farm Projects
CEC	Cation Exchange Capacity

1 Introduction

The population of Ghana counts approximately 28.8 million people of which about half resides in rural areas (World Bank, 2017). Poverty incidence is much higher in the rural population than in cities; 78% of Ghanaians in poverty live in rural areas (Ghana Statistical Service, 2014). Especially in the regions in the north of Ghana (Upper West region, Upper East region and Northern Region) poverty and hunger forms a major problem (Derbile, 2010; FAO, 2008). In 2013, only 17% of the total population of Ghana lived in these regions while it is home for 35.8% of Ghana's poor. The Northern Region alone already makes up 20.8% of the countries poor population (Cooke et al., 2016). As a common effect of poverty, higher levels of malnutrition have also been observed in these regions (Derbile, 2010; Van de Poel et al., 2007).

In 2018 the Government of Ghana launched a Zero Hunger Strategic Review report, aimed to end hunger and malnutrition and to reach food security in a sustainable way by 2030. The president of Ghana stated that the country should become self-sufficient; "*The basic objective of policy is to guarantee food self-sufficiency, i.e. that we are able to feed ourselves and wean us off the disgraceful dependence on the importation of foodstuffs we can grow ourselves*" - Nana Addo Dankwa Akufo-Addo (Abdulla, 2018). On the international market food products are traded with international currency and susceptible to shocks in foreign-food supplies (Ciceri and Allanore, 2018). To avoid increasing poverty and hunger and to reach self-sufficiency, improving agricultural productivity is of the utmost importance (Haggblade et al., 2004; Quaye et al., 2010).

In Ghana, more than 60% of the population depends on their own food production (Al-Hassan and Diao, 2007). The population of Ghana is growing with an annual growth rate of 2.2% (World Bank, 2017). This growth, however, has not been accompanied by growth in farmland, leading to a decline in the cultivated land per capita (Haggblade et al., 2004). Furthermore, small-scale farmers (henceforth smallholders) are facing many difficulties and constraints, including poor soil fertility, soil degradation, erosion, irregular climatic conditions, poor infrastructure and a lack of access to credit that prevents investments (Derbile, 2010; Laube et al., 2012; Mungai et al., 2016). The combination of poverty, limited access to markets and having difficulties in producing enough food for home consumption make rural smallholders a vulnerable group regarding food insecurity (Bacon, 2015). Towards the end of the dry season, food becomes scarce and additional food is generally bought at markets. At this time of the year, food is more expensive and the available budget for external food acquisition is often not sufficient to feed the whole household. Therefore, a period of seasonal hunger starts in which the number of meals per day is reduced until the harvest season starts and the stock can be replenished (Derbile, 2010; Pinstrup-Andersen, 2009).

The low soil fertility of the West African soils is considered to be the principal constraint to food production (Morris et al., 2007; Vanlauwe and Giller, 2006). The soils are weathered, nutrient limited, have a low organic matter (OM) content and a low cation exchange capacity (CEC). Soil fertility depletion can lead to lower crop productivity, less fodder for the livestock and less fuelwood for cooking. Additionally, reduced plant cover exposes the soils to increased runoff and degradation through erosion (Abunyewa and Mercer-Quarshie, 2004; Sanchez et al., 1997). The combination of poor soils and poverty can become mutually reinforcing, creating a ‘poverty trap’(Barrett and M Bevis, 2015). If soil degradation is not reverted, yield gaps will keep poor farmers confined in recurrent poverty traps (Tittonell and Giller, 2013). To boost agricultural productivity proper soil-fertility management, for example through the application of soil amendments, is essential.

1.1 Mineral fertilizers

The application of mineral fertilizers is one of the approaches smallholders use to increase yields. However, there are drawbacks to the use of mineral fertilizers. Firstly, the largest part of nitrogen in mineral fertilizers is based on ammonia which can result in soil acidification (Kotschi, 2013). Secondly, mineral fertilizer does not contain organic matter. Organic matter improves the physical, chemical and biological properties of soils including the binding and release of nutrients, the CEC, the moisture holding capacity, the soil structure and biological activity (Bot et al., 2005; Mariangela Diacono and Montemurro, 2010). As a result, the crop-derived carbon is often the only input contributing to the organic carbon content of the soil (Gong et al., 2012). A study in Togo has shown that annual applications of fertilizer could maintain long term productivity, but could not maintain organic matter and carbon levels (Kintché et al., 2010). Soils degraded to the point where only 20-30% of the organic matter that would be present under natural vegetation is left, have a very low potential to absorb nutrients. Most of the mineral fertilizer will, in this case, be washed out (Khan et al., 2007). The application of mineral nitrogen can also increase the decomposition rate of humus or the less stable OM (Khan et al., 2007). In turn, this reduces N-mineralization and the ability of the soil to retain N-fertilizer (Pedercini et al., 2015). Furthermore, research on savanna soils has shown that N-fertilizers deteriorate the soil physicochemical conditions of the soil in the long term (Vanlauwe et al., 2001). This especially takes place when ammonium sulphate is applied, which is the second most imported fertilizer in Ghana (Food and Agriculture Organization of the United Nations, 2005)

Difficult trade-offs have to be made to find funds for mineral fertilizers (Derbile, 2010, p. 72). When farmers do find credit to invest in mineral fertilizers, it is generally not enough to apply a sufficient amount (Bedada et al., 2014a; Chianu et al., 2012). Furthermore, the high year-to-year variability in the agronomic efficiency of fertilizers and an often adverse benefit-cost ratio between fertilizer cost and the market price for food crops discourage fertilizer usage (Morris et al., 2007; Sommer et al., 2013). The use of mineral fertilizers can lead to more production and income, making it worth the investment. However, returns are often low or variable (Sanchez et al., 1997). Even when profits can be made from the use of mineral fertilizers, other basic needs can be more pressing at the beginning of the season. This can create shortages, preventing the purchase of sufficient fertilizer. High costs, lack of credit, and delivery delays can all result in farmers not being able to apply fertilizers in recommended rates or at the appropriate time (Sanchez et al., 1997). Due to transport, distribution, and transaction costs prices of mineral fertilizers in developing countries tend to be high. The bulk of mineral fertilizers is produced and traded by a select few multinational companies. As a result, developing countries are importing and trading fertilizers in a foreign currency, and are therefore exposed to price fluctuations in mineral fertilizers of the global market. Moreover, mineral fertilizer prices are influenced by the prices of energy and oil. The price of fertilizers occasionally even rises much faster than the price of food products, which can result in fertilizer costs becoming too high in remote rural areas (Chianu et al., 2012; Khan and Hanjra, 2009; Kotschi, 2013). Nitrogen, phosphorus and potassium are all produced in just a few countries, making mineral fertilizer price and availability in developing countries also dependent on the political situation. Therefore, for the smallholder, it can be financially difficult and not very sustainable to exclusively depend on mineral fertilizer for soil fertility management.

To enable smallholders to afford mineral fertilizers, the government of Ghana has provided subsidies over the last decade. However, research has shown that mainly larger-scaled and wealthier farms benefited from these subsidies. Effective targeting of the subsidies has been proposed as a solution. However, there are major concerns regarding the feasibility due to for example implementation issues, transaction and fiscal costs, nepotism and political interference. Critique on the subsidies has been growing where scholars started to question the opportunity cost of using public resources for fertilizers (a private good) while the resources could also be invested in other interventions with possibly higher returns, like infrastructure, education, health and research (Houssou et al., 2017).

Next to financial and availability concerns, there are also some environmental concerns regarding mineral fertilizer use, such as the carbon dioxide emissions released during production, storage, transport and application. In addition to the release of carbon dioxide, nitrogen fertilization also release nitrous oxide (N_2O) gas, which has a global warming potential 310 times higher than carbon dioxide (Khan and Hanjra, 2009). The energy used to produce nitrogen is also high at 69 530 kJ/kg (Gellings and Parmenter, 2004).

1.2 Organic amendments

For small-scale farming systems to become more autonomous, the reliance on mineral fertilizer can be reduced by using local compost instead. Crop residues and farm animal manure are available on the farms and can be recycled in the system through compost. Residues are generally fed to livestock, used as fuel in the household or left on the fields to be burned. Burning is sometimes used by farmers to clear the fields for new cropping season but can also be a result of unconfined burning activities of other community members for pest control or rodent hunting (Mungai et al., 2016; Valbuena et al., 2015). There are many agro-ecological and social-economic factors influencing the use of residues, awareness of the positive effects of using residues for soil amendment being one of them (Valbuena et al., 2015).

Organic amendments like compost are considered to have many beneficial effects on soil fertility, such as increasing nutrient and organic matter content, improving soil structure and moisture retention capability, improving pH values, increasing the cation exchange capacity (CEC) and affecting the microbial community (Bedada et al., 2014a; M Diacono and Montemurro, 2010; E. Ouédraogo et al., 2001; Ros et al., 2006; Saison et al., 2006). Several studies have shown how long-term application of organic amendments not only increased nutrient availability, but also the soil organic matter content (SOC). In contrast, soils treated with mineral fertilizer did not show significant increases in SOC or even showed decreasing concentrations compared to unfertilized soils (Bedada et al., 2014a).

Mineral fertilizers generally only contain Nitrogen (N), Phosphate (P) and Potassium (K), also known as NPK-fertilizers while compost is known to also supply Calcium (Ca), Sodium (Na), Magnesium (Mg), Zinc (Zn) and Manganese (Mn) (Amlinger et al., 2007; Bulluck et al., 2002; M Diacono and Montemurro, 2010). Deficiencies in nutrients like Ca, Na, Mg, Zn, and Mn can greatly limit crop productivity (Abunyewa and Mercer-Quarshie, 2004; Kihara et al., 2017; Sommer et al., 2013). Research has shown a response to N-fertilizer can be limited, if not applied with other nutrients (Franke et al. 2008). A hampered effect of adding N, P or K can in some cases be explained by the Sprengel-Liebig Law of the Minimum stating not the total resources but the scarcest resource dictates the growth (van der Ploeg et al., 1999). If compost can be an affordable way to supply limiting nutrients, the use of compost can be a promising tool to increase nutrient content, improve soil fertility and increase yields.

Teaching and helping farmers to make and use compost could provide a promising means to increase productivity and continuity of small-scale farming systems and to reduce food insecurity. Compost can be produced and applied by farmers that lack the resources to buy mineral fertilizers but do have labour available to make compost. Based on earlier research compost-can increase soil fertility and yields, and long-term application can improve the food availability of the household (Bedada et al., 2014a; Celik et al., 2004; Ros et al., 2006; Van Haute, 2014). Excess harvest could be sold and in combination with the lower investment costs which may lead to an improved financial situation. If the financial situation can be improved sufficiently, the wellbeing of a family can improve and a higher standard of living can be attained (Nube et al., 1998). A study done in Ghana by Nube *et al.* (1998) indicated that differences in the body mass index (BMI) also reflected differences in the standard of living which suggests that the success of long-term organic amendment application programs could be measured through indicators reflecting financial and nutritional status. Therefore, the financial and nutritional status will also be incorporated in this study next to soil fertility and food production aspects.

1.3 Research objectives

In the last decade, two projects, the Zasilari Ecological Farm Projects (ZEFP) and the Sirigu Ecological Initiative for Sustainable Development (SEISUD) have worked on educating groups of farmers in northern Ghana on producing and using compost. Participating farmers have reported to the projects that they have higher food security after implementing the use of compost. Interviews from the study by Derbile (2010) indicated a positive effect of compost use on food security in the SEISUD project and several other projects. There is however no reliable quantitative information on the differences in yields between farmers that apply mineral fertilizer (also called "conventional farmers") and farmers that apply compost after receiving training (also called "organic farmers"). Currently, in the existing literature, there is overall little written on the possible benefits of compost making for rural farmers in sub-Saharan Africa. It is important to quantify these effects – a farmer will need to invest time to produce the compost, and the amount of compost that can be produced may be constrained in a certain region. More region-specific research is needed to identify effective approaches and validating the effectiveness of newly proposed tools and practices can play an essential role in fighting food insecurity. To assess whether switching to organic amendments constitutes a viable alternative to mineral fertilizers, a reliable estimate of the benefits (i.e. potential yield increases) is needed. Collection of more quantitative information is thus urgently needed.

The aim of this study is to evaluate the difference in food security between smallholder farmers that use mineral fertilizer and farmers that apply compost after receiving training. A comparative analysis of the food security of smallholder households using compost versus mineral fertilizers in northern Ghana was performed. The food security of a farmer was assessed by evaluating the following three objectives;

1) To assess three aspects of farm food production;
    a. Soil fertility (OM, Ptot, Ntot, K, Ca, Mg, Na, NH4, NO3, PH4 content and pH)
    b. Maize plant health (plant height, number of leaves, width and length of leaves, FW and DW of grain ears and number of grains per ear)
    c. The maize yields of the farms (yield per plant and yield ha^{-1})
2) To assess the health of the household members with the use of three indicators;
    a. the BMI for the adults (BMI_a)
    b. the BMI-for-age z-scores for the children (BAZ)
    c. the height-for-age z-scores for the children (HAZ)
3) To assess the financial situation (in this paper be referred to as wealth) of the household using two indicators;
    a. The invested capital in animals
    b. The invested capital in objects

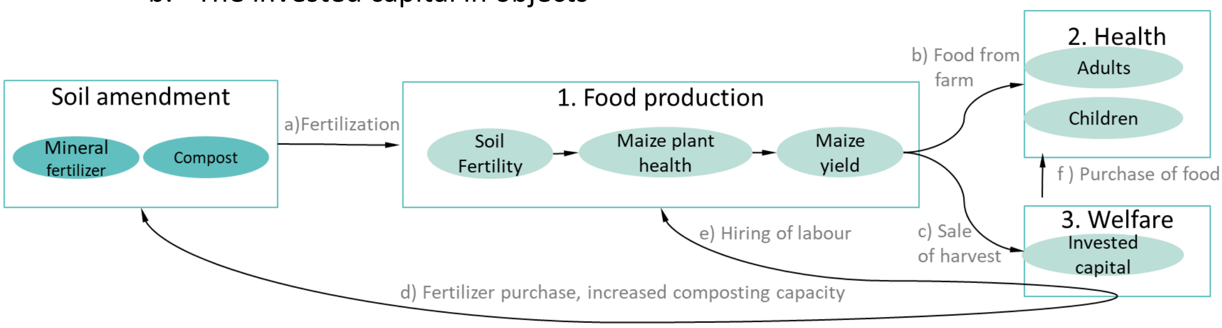

Figure 1: Visualisation of the three aspects studied in this research (food production, health, wealth) and the relationship between these aspects.

Figure 1 summarises the three studied aspects and the interactions between these aspects. It is assumed that the different soil amendments (a) influence the farmer's ability to produce food. Higher food production is beneficial for the health of the household (b) and for the financial situation of the household if part of the harvest can be sold (c). A better financial situation can boost productivity by the purchase of fertilizer or increasing the capacity to make compost (d) and by the hiring of labour for plant care (e). Furthermore, can an improved financial situation improve the health of the family by allowing the purchase of food products at the market (f). The relationship between these aspects was evaluated using a principal component analysis (PCA) and mixed linear regression analysis. The study of Fröndt (2018) showed that composting strengthened social cohesion and therewith increased a feeling of togetherness, harmony and social responsibility. Such social interactions are not included in Figure 1 although they could have an influence on the food security of a household.

2 Methodology

2.1 Study site

The research was conducted in five communities in north of Ghana; three in the Northern Region and two in the Upper East region. The north is characterized by low humidity, periods of severe drought and savannah vegetation (Van de Poel et al., 2007). Data collection was done at the end of the wet season (September 2016 -January 2017) when most crops are also harvested. Small-scale mixed rain-fed agriculture is the common farming system with the focus on grain cropping and livestock production. The soil is left bare after the harvest until thee raining season begins again and annual crops are sown. In this period, early rains tend to erode the soils (Aniah, 2013)

The three communities in the Northern Region were Guabiliga (10° 24'53.4'' N & 0° 41' 39.1'' W), Nayawko (10° 23' 40.4'' N & 0° 42' 22.9'' W) and Zangum (10° 24'1.3'' N & 0° 49' 3.8'' W). All these communities were located in the West-Maprusi district. The West-Maprusi is located in the Northern Region of Ghana. The farmers in these communities have been trained by ZEFP. The Northern Region makes up the largest number of poor people (1.3 million) of Ghana's then regions. This region also has seen the smallest progress in poverty reduction, with poverty rates of 50.4% (Cooke et al., 2016). The elevations in this district vary between 140m and 190m above sea-level. In this region, the climate is dry with one wet season from May until October. The amount of annual rainfall varies between 750mm and 1050mm. During the dry season (harmattan) temperatures can vary between 14°C at night and 40°C during the day (Government of Ghana, n.d.).

The two communities in the Upper East Region were Nyangolingo Anongtaaba (10° 58' 9.2'' N & 0° 55' 17.7'' W) and Yua (10° 58' 44.5'' N & 0° 54' 40.1'' W), both located in the Kassena Nankana district. The farmers in these communities have been trained by SEISUD. Additional information on the composting project of SEISUD can be found in the thesis of Maira Fröndt (Fröndt, 2018). In 2013, 44.4% of the population in the Upper East region lived in poverty (Cooke et al., 2016). The elevations in this district vary between 208m and 210m above sea-level. The wet season in the Upper East region is from May/June to September/October and is generally shorter than the wet season in the Northern Region (Government of Ghana, n.d.). The amount of annual rainfall varies between 800 mm and 1300mm. The annual mean temperatures is 28.6°C but during the dry season, the average temperature exceeds 32°C (Government of Ghana, n.d.; Laube et al., 2012).

2.2 Farm selection

In every community, three conventional farmers and three organic farmers were initially selected. All farmers in the Northern Region were required to cultivate maize and all farmers in the Upper East region were required to cultivate millet. For the selection of the organic farms, only farms were chosen that indicated to have exclusively applied compost as a fertilizer in the past four years and did not use chemical pest control. The selected conventional farmers exclusively used mineral fertilizer and had not used compost in the known past. In some cases, these farmers also used chemical pest control. Three farmers were excluded from the study; one farmer could not be considered a smallholder farmer due to his wealth and land area, one organic farmer used mineral fertilizer on his rice field and one farmer left the region during the research period. A total of 27 farmers participated of which 14 were considered organic and 13 were considered conventional (n_{total}= 27, $n_{conventional}$ = 13, $n_{organic}$= 14). The farmers in the Northern Region mainly fertilized their maize fields and the farmers in the Upper East region mainly fertilized their millet fields. It was not possible to collect reliable data on millet production and therefore, only the farmers in the northern region were considered for food production regarding maize health and maize yield and were included for the linear regression analysis.

2.3 Food production

2.3.1 Soil Fertility

To measure soil fertility, soil samples were taken for analysis. Soil samples were analysed for bulk density, texture, pH, organic matter content and nutrients (Ptot, Ntot, $N\text{-}NO_3$, $N\text{-}NH_4$ and $P\text{-}PO_4$, K, Ca, Mg and Na). Soil sampling was done on the field the farmer perceived as the most important, often close to the compound. Fields close to the compound are the safer ones, as there the crops are better protected against livestock or theft(Tittonell and Giller 2013, personal experience). Soil texture was determined through a decision tree based on visual and physical properties of the sample by feel (Ritchey et al., 2015). To calculate the bulk density one or two samples, depending on the size of the field, were taken using a metal tube with a diameter of 7 cm and a length of 10 cm. The soil was weighed immediately after collection, after air drying at approximately 40°C. On the same location, 10 soil samples were taken using a zigzag sampling pattern (Figure 2) (Northern Region; n_{farm}=17, Upper East region: n_{farm}=10). Soil samples were taken from the top 10 cm of the soil with a metal tube with a diameter of 3.5 cm and air-dried at approximately 40°C immediately after collection. For every farm, one composite soil sample was shipped to the Netherlands for further laboratory analysis. In the laboratory, soil samples' $pH\text{-}H_2O$ and pH-KCl were measured with a pH/mV meter. The organic matter content was measured gravimetrically by heating the soil overnight at 550 °C and measuring the weight loss. The total N and P was measured spectrophotometrically with a segmented-flow system (Skalar san++ system) after digestion with a mixture of H_2SO_4-Se and salicylic acid as described by Novozamski et al (1983). The plant available $N\text{-}NO_3$, $N\text{-}NH_4$, and $P\text{-}PO_4$ were quantified spectrophotometrically with a segmented-flow system (Skalar san++ system). The method as described by Houba et al. (2000) was followed where in this study the samples were dried at 400°C and extracted in H_2O. In the same extracts K, Ca, Mg, and Na were measured using a fast-sequential atomic absorption spectrometer (Varian AA240FS).

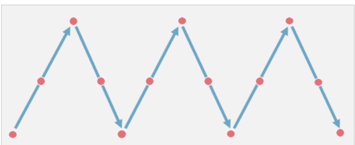

Figure 2. Zigzag Pattern used for sampling

2.3.2 Maize plant health

The maize plant health was determined for maize plants growing In the maize field the farmer considered to be the most important which was the same field as where the soil samples were taken. In the field, 10 mature plants were selected according to a zigzag pattern (Figure 2, n_{farm}=17). As a measure for maize plant health, plant height and ear weight were taken. Plant height was measured from the base (start of the roots/soil) to the top of the plant and the number of leaves was counted. For every 6th, 7th or 8th leaf the leaf width and length was measured, depending on which leaf was still intact. Of every plant the ear was harvested. The fresh weight of the pealed ears was measured and the number of seeds per ear was counted. The total weight of the grains from the 10 ears was measured and transformed into an average grain yield per plant (kg).

2.3.3 Yield

In semi-structured interviews, farmers (n=27) were asked which crops they cultivated which was summed into the number of cultivated crops. Of these crops harvest was tracked, but not used for further analysis (as explained further in the appendix, page 40). In the Northern Region Maize was considered as the most important crop. Two methods were used to assess the maize yield; in-field measurement and weight after the harvest. The first was assessed to be most reliable and used for further analyses (as further explained in the appendix, page 40). The measurements were done three or two weeks before harvest. To estimate the number of plants per hectare all maize plants carrying an ear (no plants with multiple ears were found) were counted in a representative plot of 100m^2 (10x10m). The maize grain yield per hectare was calculated by multiplying the grain yield per plant (calculated through the maize plant health measurements) with the number of plants per hectare. Total yield was calculated by multiplying with the field size, determined using a GPS-tracker (Garmin E Trex 10).

2.4 Health

Every person living for most of the year in the household of the farmer was weighed and measured (n=211). For adults (≥ 18 years, n=91), the BMI_a (Body Mass index, representing the ratio of weight and height) was used as an indicator to estimate the health of the household. The BMI is used to classify underweight and overweight in adults and is calculated by dividing the weight in kilogram by the height in meters squared. A BMI value below 18.5 kg/m2 indicates adult underweight and a BMI above 25 kg/m2 indicates overweight (Zereyesus et al., 2014). Pregnant women were excluded from the BMI calculations. One adult with unusual weight and height (1.41, 78 kg, 20 years) was removed. For the children two outliers with unusual weight and height were removed (104 cm, 30 kg and 145cm, 19kg). For the children the z-scores were calculated with the use of reference data supplied by the World Health Organization (WHO, 2013). By using z-scores the BMI and height of children is compared with the median z-scores of children of the same age in the reference data. The deviation from the median is used to determine whether the children are underweight or overweight. The z-scores from the WHO can only be used for children older than 5 years, therefore children younger than 5 years were excluded. The BMI-for-age z-scores (BAZ) and height-for-age z-scores (HAZ) were calculated for children from 5 to 17 years old (n=119). For BMI for age z-scores, the WHO uses a cut-off point of -2 to classify moderate to severe undernutrition (Onis and Blössner, 1997).

2.5 Financial situation

Interviews were held with the farmers on expenses and income (Appendix, page 47). The interviews were excluded from analysis because some of the answers of the farmers were unrealistic or inconsistent when questions were asked again at a later point in time. For the financial situation, the analysis is therefore only based on the possessions. To determine the possessions of a farmer, farmers were asked for a series of objects and animals the quantity the farmer possessed of that object/animal (Table 6, Appendix 44). The number of animals and objects were corrected for their monetary value in Ghana cedi (₵), giving an indication of the capital that was invested in the asked animals/objects.

2.6 Statistical analyses

For food production and wealth the difference between the organic and conventional farms was tested with linear regression models containing a dummy variable for farm type (organic or conventional), and correcting for village effects. For household health (adults and children), the farm type effect was also adjusted for the confounders farm ID (farm number), sex, age and family size. All confounders were implemented as random effects. In this study a p-value <0.05 was considered statistically significant.

Multivariate linear regression was performed to examine linkages between soil fertility, maize plant health, yield, human health and wealth as displayed in Figure 1. To reduce the number of parameters for soil fertility and maize plant health, a PCA for maize health and a PCA for soil nutrients was performed (Table 7 and Figure 13, page 46). The components with an eigenvalue above one were then used to describe the variation in these datasets and were used for the integrated PCA and the linear regression analysis. Regression analyses were done with either plant health, maize yield, BMI_a, BAZ, HAZ and wealth as the dependent variable. A principal component analysis (PCA) was performed to explore the trends and correlation structure between the three studied aspects (Figure 1) and to explore which variables differentiate organic farms from conventional farms. The methodology and results of this analysis is available in the appendix (section 7.2.5, page 45).

Normality was tested with the Shapiro-Wilk test. For normally distributed data the Levene test was used to test the homogeneity of variances, otherwise the Fligner-Killeen test was used. Mardia's multivariate test to test multivariate normality and the Box's M test was used to test the equality of covariance matrices. Pearson correlation coefficient was used to detect multicollinearity.

The statistical analyses were performed with the statistical program R (R Core Team, 2017). Testing of the assumptions and analyses were done with the help of the packages "car" (Fox and Weisberg, 2011), and "Rcmdr" (Fox and Bouchet-Valat, 2018), "nlme" (Pinheiro et al., 2019), "lmerTest" (Kuznetsova et al., 2017), "FactoMineR" (Le et al., 2008) and "stats" (R Core Team, 2017). The z-scores were calculated with the R-script provided by the WHO (WHO, 2013). Graphs were made with the use of the "ggplot2" (Wickham, 2016), "ggsignif" (Ahlmann-Eltze, 2017), "ggpubr" (Kassambara, 2018), "factoextra" (Kassambara and Mundt, 2017), "ggbiplot" (Vu, 2011) and "corrplot" (Wei and Simko, 2017). Other used packages include "reshape" (Wickham, 2007) and "dplyr" (Wickham et al., 2018).

3 Results

In this chapter the results for the three research objectives will be presented; food production, household health and wealth. Lastly the results of the linear regression analysis connecting these three components will be presented. The results for food production, household health and wealth are shown in graphs. Numerical values for these sections and the principal component analysis can be found in the appendix (section 7.2, starting from page 40).

3.1 Food production

In this section, three components of the food production system will be assessed; soil fertility; maize plant health and maize yield. The aim is to examine if the organic farms perform better than the conventional farmers on these three components aspects.

3.1.1 Soil fertility

The soil type of the farms was loamy sand in the Northern Region and sandy loam in the Upper-East region. No significant differences were found for the tested soil nutrients and soil characteristics between the conventional and organic farmers for neither the farms in the Northern Region or the farms in the Upper-East region (Figure 3). Interestingly, there were significantly more farmers that had soils with a pH below 6 when they applied extra ammonium sulphate fertilization compared to all the farmers that did not apply ammonium sulphate (χ^2 (df=1)= 4.86, p=0.028).

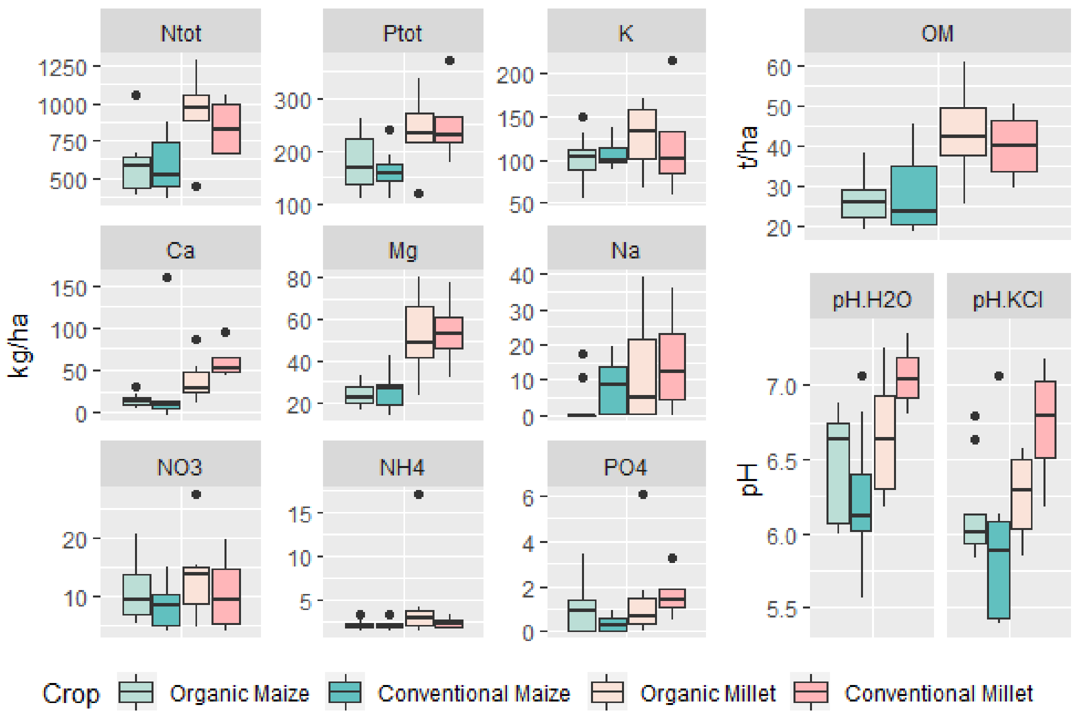

Figure 3. Boxplots of the soil characteristics and soil nutrients for the fields from conventional (n=8) and organic (n=9) maize fields from farmers in the Northern Region or, from conventional (n=4) and organic (n=6) millet fields from farmers in the Upper-East region. Displayed soil nutrients are total nitrogen (N_{tot}), total Phosphorus (P_{tot}), Potassium (K), Calcium (Ca), Magnesium (Mg), Sodium (Na), Nitrate (NO_2), Ammonia (NH4) and Phosphate (PO_4) expressed in mg/Kg. Displayed soil characteristics are organic matter (OM) content expressed in g/KG and the pH determined in water (pH.H_2O) or in potassium chloride (pH.KCl).

A significant difference was found for the number of leaves, the average leaf width and length, the fresh weight of the ear and the dry weight of the grains with the organic group performing better. The mean plant height and number of grains was also higher for the organic farms, but no significant difference was found for these characteristics (Figure 4).

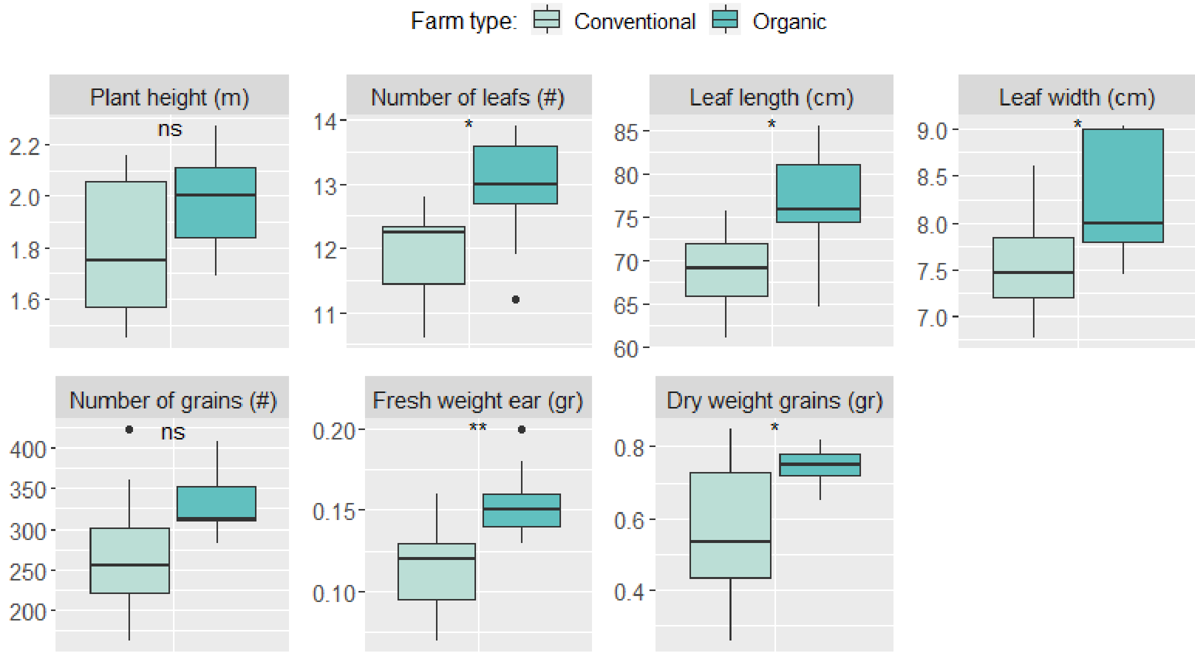

Figure 4: Average values for the plant height (m), number of leaves (#), leaf length (cm), leaf width (cm), number of maize grains (#), the fresh weight of the ear (gram) and the dry weight of the grains (gram). All values are the average of 10 plants from the main maize field from conventional farms (n=8) or organic farms (n=9) from the Northern Region.

3.1.2 Maize yield

There was a significant difference in the calculated grain yield per hectare (t_{15}=2.61, p=0.02) and the average yield per plant (t_{13}= 2.91, p=0.012) between the organic and conventional farms (Figure 5). The yield per hectare was lower in the conventional group (1155 ± 544 kg/ha, n=8) compared to the organic group (1846 ± 544 kg/ha, n=9), a difference of 688 kg/ha. The yield per plant was also lower in the conventional group (56.25 ± 20.21 gr/plant, n=8) compared to the organic group (74.33 ± 5.59 gr/plant, n=9). There was no significant difference in the number of plants per hectare (t_{13}=1.34, p=0.204) between the conventional group (20,438 ± 7000 plants/ha, n=8) and organic farms (24,889 ± 6918 plants/ha, n=9).

The data implies that the overall yield was higher on organically amended soils than conventional soils. The higher production rate was mainly driven by all individual organic plants growing relatively well, comparable to the best performing plants in the conventional fields (Figure 5). The density of plants was statistically indistinguishable across farming methods.

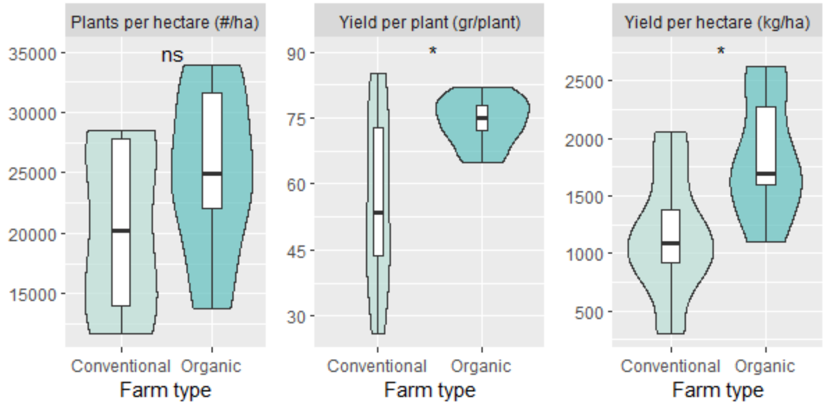

Figure 5: Boxplot and violin plot for the number of plants per hectare (#/ha), average grain yield per plant (gr DW /plant), and total calculated grain yield per hectare (kg DW/ha) of the main maize field of farmers in the Northern Region using mineral fertilizers (Conventional, n=8) or organic fertilizers (Organic, n=9).

3.2 Health

3.2.1 Adults

No significant differences were found for the BMI_a (t_{22}=-0.33, p=0.747) from conventional (24.11 ± 4.73) and organic farms (23.19 ± 2.53) for neither males or females (Figure 6A). Most adults were considered healthy. Four adults (10.5%) from the conventional farms and one adult (1.9%) from the organic farms were underweight (difference between farm types not significant: χ^2 (df=1)=3.10, p=0.078). In contrast, obesity was observed for 16 adults from conventional farms (42.1%) and for 11 adults from organic farms (21.2%). This difference between farm types is significant in the chi-square test (χ^2 (df=1)=4.59, p=0.032).

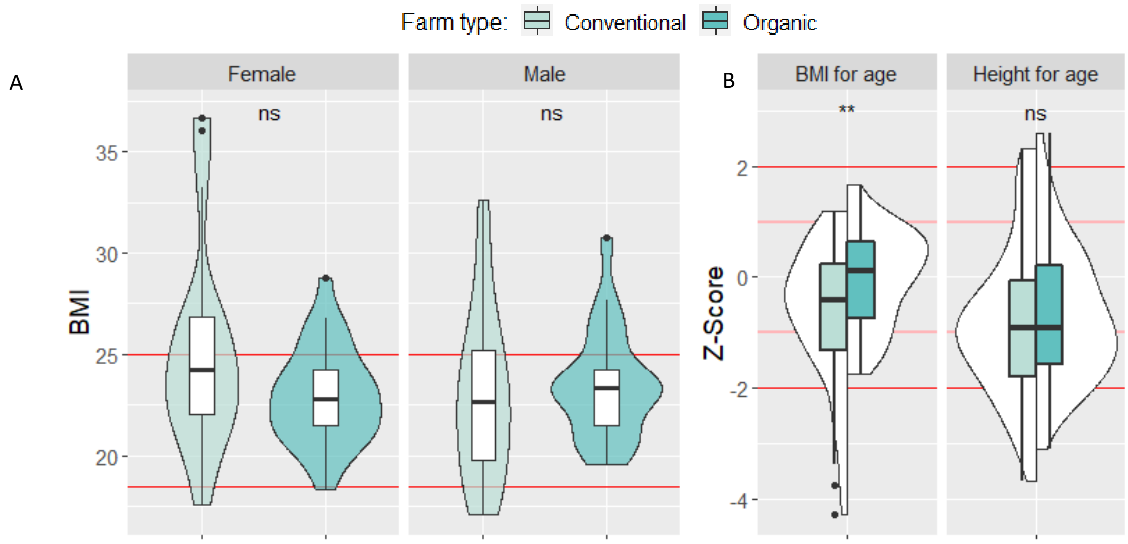

Figure 6. A) Boxplot and violin plot for the body mass index (BMI) of adult females and males from farms using organic ($n_{females}$=30, n_{males}= 22) or mineral fertilizers ($n_{females}$=20, n_{males}= 18) Red lines demarcate the range of healthy BMI values. B) Boxplot and violin plot for the z-scores for BMI-for-age and height-for-age (HAZ) (from households applying mineral fertilizer or organic fertilizer ($n_{organic}$= 46, $n_{conventional}$=47). Pink lines demarcate the range of healthy BMI values. Children with z-scores outside of the red lines are considered overweight (z>2) or underweight (z< -2) (Onis and Blössner, 1997).

3.2.2 Children

For the children, a significant difference was found between the groups for the z-scores of the BMI for age (t_{22} =2.19, p=0.039) with the organic group (-0.02 ± 0.87, n=46) having a higher z-scores then the conventional group (-0.69 ± 1.28, n=47, see Figure 6B). Furthermore, 7 children were underweight from the from conventional farms (14,9%) whereas none of the children from organic farms were underweight This difference is also significant in the Fisher exact test (p= 0.0123).

No significant differences were found for the height for age (t_{22}=-0.22, p=0.827) (Figure 6B). For the conventional farms 8 children showed stunted growth (17%) and for the organic farms 6 children (13%). All children combined, 15.1% of the children had exhibited stunted growth. A mean of 0 for the height-for-age z-scores would reflect a normal, healthy, population where the child population of this research had a mean of -0.741.

3.3 Financial situation

There were no significant differences between the conventional and organic farms for neither capital invested in animals (t_{21} = -0.90, p=0.376) nor capital invested in objects (t_{21} = -0.09, p=0.933, see Figure 7).

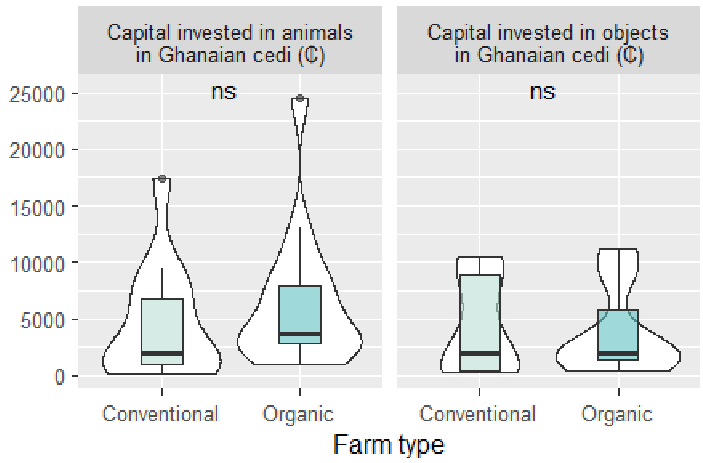

Figure 7. Boxplot and violin plot for the capital invested in Ghanaian cedi (₵) in either animals or objects by the conventional and organic farms.

3.4 Interactions between food production, health and wealth

A linear mixed model analysis was performed to assess the interactions between the three factors as displayed in Figure 1 (n=17). The dependent and independent variables used in the mixed models can be found in Table 1.

For the maize plant health and soil nutrients a PCA was performed to reduce the number of variables for the linear regression analysis. From the soil nutrient PCA the first three components were used (with eigenvalues of 3.9, 2.52 and 2.25) which together explained 72% of the variation in the soil fertility dataset (Figure 10 and Table 3, appendix page 42). For maize plant health the first principal component (named plantPC1, eigenvalue of 2.17) was used, explaining 67% of the variation in the maize plant health dataset (Figure 11 and Table 5, Appendix page 44).

For maize plant health (plantPC1) the results showed an association with farm type (e.g. conventional/organic, p=0.002) and a negative association with soilPC2 (p=0.002). SoilPC2 was negatively corelated with concentrations of OM, Ptot, Ntot, Ca, Mg, NO3, NH4 and the pH and positively correlated with Na (Table 3, Appendix page 43). For maize yield, the maize plant health showed a significant association (p=0.002). There is no indication of wealth having a significant effect on the food production and none of the independent variables explained the variation in wealth (capital invested in animals and objects). Therefore, the analysis for wealth is not shown. For the BMI_a, BAZ and HAZ an association was found with the invested capital in objects (p=0.067, p=0.011 and p=0.042 respectively). A relationship was found between farm type and BAZ (p=0.002) and between yield and HAZ (p=0.011). For BMI_a and BAZ a negative relationship was found with the number of crops (p=-0.031 and p=0.014).

Table 1 Results of the linear regression analysis with plantPC1, maize yield, BMIa, BAZ and HAZ as response variables for the conventional (n=8) and organic farms (n=8) from the Northern Region. Only the results for the explanatory variables that showed a significant interaction with the response variable are shown. The last two columns show the explanatory variables and random effects that were included in the model.

Response variable	Explanatory variables (significant)	Estimate	SD	Pr(>t)		BIC	Explanatory variables in model	Random effect(s)
PlantPC1								
	Intercept	-1.20	0.45	0.018	*	64.30	Farm type, Animals, Objects, soilPC1,soilPC2, soilPC3,	Village
	Farm type	2.27	0.62	0.003	**			
	SoilPC2	-0.77	0.20	0.002	**			
Maize yield/ha								
	Intercept	1521.16	114.24	1e-09	***	263.9	Farm type, Animals, Objects, soilPC1, soilPC2, soilPC3, plantPC1	Village
	PlantPCA1	203.98	54.21	0.002	**			
BMIa								
	Intercept	0.536	0.289	0.076	.	273.8	Farm type, Maize yield, Objects, Animals, Number of crops	Village, Farm, Age, Sex, Family size
	Number of crops	-0.068	0.030	0.031	*			
	Objects	0.230	0.116	0.067	.			
BMI for age								
	Intercept	-0.749	0,33	0.055	.	234.9		
	Farm type	1.672	0.472	0.002	**			
	Number of crops	-0.723	0.257	0.014	*			
	Objects	0.507	0.187	0.011	*			
Height for age								
	Intercept	0.033	0.276	0.913		228.8		
	Maize yield	0.298	0.115	0.011	*			
	Objects	0.294	0.141	0.042	*			

4 Discussion

4.1 Main findings

4.1.1 Soil fertility

No significant differences in the soil nutrients and characteristics were found between the soils of the conventional and organic farmers. Based on the linear regression model (Table 1), soil fertility is correlated with plant health. There was a negative correlation between soilPC2 and maize health. This means that farms with higher soilPC2 values usually have lower OM, P_{tot}, $N_{tot,}$ Ca and Mg concentrations (Table 3), and also with lower maize plant health. Ca and Mg are cations and soils with a higher cation exchange capacity have a higher ability to absorb these cations. Possibly differences in CEC and organic matter (known to have a positive effect on the CEC of soils (Oorts et al., 2003)) are associated with the soilPC2. High soilPC2 values seemed to occur more among the conventional farmers (Figure 13) but no significant difference was found between the two farm types. More data is needed to explain which factors drive the variation in soilPC2.

Regarding pH, no significant differences were found between conventional and organic farms. The pH is of interest considering that the CEC of a soil decreases when the pH of a soil decreases (increased acidity). Especially for the farmers that applied ammonium sulphate next to NPK-fertilizer it might be advisable to consider the pH in the field management. Significantly more ammonium sulphate fertilised fields had a pH below 6 compared to all the fields without ammonium sulphate fertilization. Ammonia is known to lower the soil pH and at a pH below 5.5 aluminium toxicity can become a problem to plant growth and phosphorus becomes less available (KISINYO et al., 2014; Kotschi, 2013). Ideally, the farmers would neutralise the acidification with liming. However, for smallholders this would be another expense they might not be able to afford.

It should be noted that soil samples were taken at the end of the growing season. Fluctuations in pH and nutrients during the different season where not recorded. Furtheremore, soil sampling took place after plant growth and nutrient uptake. Therefore, it seems that the higher maize production on the organic fields did not deplete the nutrient pools to lower levels compared to the conventional fields. Possibly, there has been a difference in the nutrient pool at the start of the growing season with the organic fields containing higher nutrient concentrations. The fields in the Upper East region, where millet was cultivated, seemed to have a higher soil fertility compared to the maize fields from the Northern Region (Figure 3). Based on the findings of Van Duivenbooden *et al.* the difference is probably not explained by the uptake and nutrient content of the different crops (maize versus millet)(Van Duivenbooden et al., 1996). Possibly the difference is caused by geography, erosion processes or past land management.

Both groups applied a limited amount of nutrients to their fields resulting in minor differences between the groups. The conventional farmers in this study considered mineral fertilizers expensive and said that it was hard or impossible to free money to invest in mineral fertilizers (Haggblade et al., 2004). This results in many smallholders not being able to purchase adequate quantities of mineral fertilizers. Only few farmers were able to give reliable estimates of their fertilizer use, estimated to range around an average nitrogen application of 50 to 80 kg N/ha. Some of the farmers in this research used as little as 10% of the recommended amount (120 kg N ha-1). Several studies report the same issue (Chianu et al., 2012; Palm et al., 2007); a study done in Nigeria reported that up to 81% of the fields received less than half of the recommended amount (Manyong et al., 2001). A similar issue can be found for the farmers using organic amendments. Many interviewed farmers stated they are not and will likely never be able to make and apply compost on the whole farm. For example, cow dung and crop residues are also used as fuel for cooking, animal feed or for building purposes (Palm et al., 2007; Quansah et al., 2001). A drawback in the use of organic amendments is the limited availability of organic material. The low nutrient concentration (N, P and K) of organic inputs when compared to mineral fertilizers is often used as an argument against organic fertilizers. To meet crop requirements the N, P and K content of plant residues is normally insufficient (Ciceri and Allanore, 2018; Sanchez et al., 1997). Assuming a donkey cart contains 100kg of compost (Defoer et al., 1998), the five farmers that gave the most reliable information on their compost application fertilized their fields with approximately 1.5 tonnes of compost/ha. Assumed that the N-concentration of the compost is around 1% (Abdou et al., 2016; Wind-Tinbnoma Kaboré et al., 2009), the farmers are applying 15 kg N/ha per year. The plants receive even less of of this estimated amount per year because farmers generally apply compost only on a part of the field and these specific plots are fertilised once every three years for some of the farmers. The organic fields therefore receive a much lower nitrogen application compared to what the conventional farmers indicated. Based on these estimates of nitrogen application it is striking that the nitrogen content of the organic fields was not significantly lower compared to the conventional farmers. Some farmers hypothesised that not all the mineral fertilizer applied by the conventional farmers was retained by the soil, partly due to runoff. In the north of Ghana rainfall intensities are indeed high, exceeding the soil infiltrability, causing runoff and erosion (Aniah, 2013). Possibly the compost application has improved some soil characteristics not measured in this study like soil structure, soil surface area, CEC and hydrological properties causing the nutrients that are applied to also be retained by the soil. For future research it would be of interest to investigate if there is difference in soil fertility between the two treatments when more soil characteristics are evaluated or when other methods to determine the OM-content are used.

4.1.2 Maize plant health and yield

The maize plants that received organic fertilization performed better than the plants recieving mineral fertilizers (Figure 5). Most of the measured plant characteristics showed a significant or marginal significant difference between the two groups, with the organic group performing better. The results imply that the plants growing on organically amended soils developed larger photosynthetic capacity by growing more and larger leaves, rather than growing taller. It seems that this growth response was associated with the production of larger grains, rather than producing more grains. This response increased the dry weight of the grains and the fresh weight of the ears. In conclusion, the results suggest that the training provided by the NGOs ZEFP has had a positive effect. This study was not able to identify yield increases for the farmers in the Upper East region, trained by SEISUD. However, in the study done by Fröndt (2018), farmers part of the SEISUD project stated that the organic farmers have a better reputation in the community after becoming part of composting groups because they are food secure, do not ask others for food and help others to become food secure as well.

The differences in maize plant health and yield might have been caused by the differences in soil fertility, as discussed in the previous section. Apart from the fertilization scheme, benefits from being connected to an NGO could also have influenced the difference between the two groups. A study done by Issaka *et al* (2016) also included farmers trained by ZEFP. They mention that collaborating with an NGO gives the farmers access to information and technical support. Furthermore, being connected to NGOs seems to promote the formation of farmer groups. Within these groups, production constraints can be discussed and collectively addressed. For example, labour shortages can be addressed by exchanging and organising support labour to each other's farms in turn. In this way weeding, planting, and harvesting can be done at the right time and at a lower cost (Issaka et al., 2016).

The food production is an indicator of food availability and therefore of food security. However, due to complex social dynamics, the size of the harvest does not fully reflect how much of this harvest is also actually eaten by the household. Some of the farmers mentioned they sell part of their harvest even when they do not have surpluses. Farmers can sell crops when prices are low because they are in acute need of money (school fees, medical costs). This can force them to rebuy food in hunger season when prices are much higher. Interestingly, Shipton mentioned a few other reasons for this process to occur that gives insight into the complexity of assessing food security*; "Selling heavily after harvest lets one push storage risks onto buyers. And one can ... invest in a cow, an iron roof, or a bicycle without looking selfish to needy relatives and neighbours, as one would seem by selling grain for such things in the hungry season. Also, exchanging grain for a less liquid, less divisible asset like large livestock shelters wealth from daily demands for sharing or sales. ... The "squawk factor" - the potential for complaints and damaging accusations-underlies every saving or investment decision. Since social ties are also investment or insurance, it can make more sense to sell cheap and buy dear than to try to wait and sell dear. In Africa as everywhere, however, what is good for an individual may not be good for a class or other aggregate."* -(Shipton, 1990, p. 367). Sharing and social investment further influence the destination of the harvest. Social investment can be defined as '*giving, sharing, or lending to others with expectation of direct or indirect return"* --(Shipton, 1990, p. 368). Shipton explains that rural Africans tend to spread their investments widely creating social and political networks of alliances they can rely on in emergencies. In other words, part of the harvest might be given away or received from another household in turn for other services or products. Therefore, the harvest tells us something about the means they will have to feed the family, but not per se in how much food the household will also consume. Lastly, after harvest the funeral season begins which are occasions for a family to earn social prestige. The family of the diseased is expected to serve food to all the visitors and well visited, good funerals, including an abundance of food, are a sign of wealth while poor funerals are seen as a disgrace (de Witte, 2008). Criticism on the extravagant funerals is growing partly due to the expenses made, sometimes exceeding a family's capacity resulting in dept (van der Geest, 2006). Research should be done on the food waste resulting from funerals and the impact of funerals on the food security of families. In conclusion, intricate social dynamics make it almost impossible to assess how much food a household has to their disposal throughout the year and can only serve to give us an indication.

4.1.3 Household-health

The children from the organic farmers had a significantly higher BMI for age. All children from organic farms had a healthy BMI for age. On the contrary, children from conventional farms showed some signs of unhealthy BAZ with 14.9% of the children being underweight. A low weight-for-height indicates wasting or thinness, often associated with starvation or disease (Onis and Blössner, 1997). The difference between the two groups could indicate that the families from the organic farms were able to provide a more adequate diet to their children. This is in line with the earlier findings (Figure 5) that organic farms reached higher maize yield.

No significant differences were found for the height-for-age of the children between the two farm groups. This is not surprising since stunting is a "cumulative process reflecting chronic undernutrition over time" (Ruel et al., 2018). For children to catch up on growth retardation, sufficient food would have to be provided. Several studies pointed out that an improvement of dietary diversity or child undernutrition cannot be achieved by growth in income or agricultural production alone (Ruel et al., 2018). Even if the organic farmers reach higher yields, it is unlikely that this difference would be large enough to compensate for the already established effects of chronic undernutrition. Furthermore, most organic farmers have only applied compost for the last few years and therefore most children have grown up in a situation where compost was not yet used and could not have benefited them.

In this study, the z-scores for height-for-age indicate that many children are dealing with stunted growth. Stunted growth can be associated with suboptimal health and/or nutritional conditions. This suggests that most, if not all, children in this study could be coping with a compromised nutritional status, even when many have a healthy BMI (Onis and Blössner, 1997). The high prevalence of stunting in the child population of this study is worrying since young children are especially vulnerable to malnutrition. Infants may not fully recover from malnutrition with long-term effects on mental development. In turn, this can lead to reduced learning abilities in school and a poor work capacity later in life (Bain et al., 2013; Onis and Blössner, 1997). Other evidence stresses that malnutrition in childhood can lead to a higher risk of obesity and chronic diseases in adulthood (Fotso, 2007). These results stress the importance of the presence of NGOs in this region to capacitate farmers to produce enough food to feed their children adequately. Next to increasing the farm productivity, education could help to reduce malnutrition and improve the household health status through for example education on nutrients, vitamins improved hygienic conditions and the prevention of parasites and disease. Education could also help to reduce family sizes to match resources, allowing adequate and quality nutrition to every family member (Bain et al., 2013). Potentially and ideally, programs like SEISUD and ZEFP could include education on these aspects in their programs. Research has shown that especially educating and empowering women has positive effects on a child's nutritional status, which could be included in training programs as well (Ruel et al., 2018).

No significant differences were found for the BMI of the adult population. Only a few adult individuals were considered underweight or overweight. For adults from conventional farms, more adults were overweight. This difference between the two farm types cannot be directly explained based on the collected data. Possible explanations could be either coincidence, differences in physical activity or differences in diet. In contrast to the expectations, more adults were overweight than underweight. A high BMI can be (but is not necessarily) an indicator of obesity. Some of the overweight adults came from families where undernutrition was present among the children. This 'paradoxical phenomenon' has been documented by other studies (Garrett and Ruel, 2005). It is hypothesized that the presence of under- and overweight individuals in the same household can be a symptom of a "nutrition transition" which could be defined as "a wave of change in diet, physical activity, and body composition patterns that a country goes through on the road to higher levels of economic development" (Garrett and Ruel, 2005). Several studies indicated rising rates of obesity in urban Africa (especially amongst women) which is thought to be associated with urbanisation and the adopting a more western lifestyle ('westernization') (Abubakari et al., 2008; Amoah, 2003; Benkeser et al., 2012; Dake et al., 2011; Oniang'o et al., 2003). In urban Africa processed food and snacks are becoming a part of the daily diet. Western food products like cookies and soda were available in the villages where the research was conducted but it was not assessed whether the members of the households of this study consumed untraditional food products. Snacks have a higher proportion of fat, starch, and sugar compared to traditional food. An excess of fats, starch, and sugar can be stored as body fat and in turn can lead to higher BMI values (Oniang'o et al., 2003). It is believed that poverty can lead to compromising diet quality, also called the poverty-obesity paradox, due to food high in fat and carbohydrates becoming cheaper compared to food with a higher nutrient density like vegetables, fruits, and whole-grains.(Tanumihardjo et al., 2007). The existence of a poverty-obesity paradox in Northern-Ghana has been suggested by Dake *et al*. (2011). It should be noted that the abovementioned studies indicated a lower risk for obesity for the rural population and individuals with limited food security, although, Garrett and Ruel (2005) found that the presence of underweight children and an overweight mother in the same household was not associated with urbanisation, but with economic development. Other explanations for a rise in obesity could include the increase in using of public transport instead of walking and the increase in watching television and associating 'fatness' with success and beauty (Amoah, 2003).

4.1.4 Financial situation

There was no significant difference between the grain yield per hectare and the financial capital in animals or objects between the farm types. This suggests that none of the farm methods has made the farmers financially more prosperous than the other. Furthermore, the results suggest that the presence of an unfair difference between the two groups, with one group being wealthier and having an increased investment capacity, can be excluded.

4.1.5 Interactions

The linear regression model showed that next to the farm type, variation in soilPC2 also explained part of the variation in plant health. It is possible that the farm type also reflects differences in plant care (planting, weeding) because of the social effects (farm groups) and access to information (due to connection with NGO). The plant health explained the variation in maize yield, which is in line with the expectations (Figure 1).

The results suggested maize yield is associated with HAZ, supporting the expected link between food production and household health. Possibly the farms with a higher yield (both conventional and organic) have reached higher yields consistently over the years, resulting in a lower prevalence of stunting. This relationship does not reflect any differences between the groups but does suggest that children might indeed benefit from higher productivity. The farm type did explain part of the variation in BAZ, which is in line with the findings for BAZ (Figure 6B) of this study. A negative relationship was found between the number of cultivated crops and BMIa and BAZ. Considering the limitations of this study I am hesitant to speculate on possible explanations. Earlier findings show a linkage between production and consumption, with farm production diversity leading to increased household dietary diversity (Ecker, 2018; Ruel et al., 2018). For future research, it might be of interest to explore the effect of farm diversity on dietary diversity and health.

The invested capital in objects explained part of the variation in the BMI_a, BAZ and HAZ and therefore there might indeed be a connection between wealth and health. This is in line with the work by Headey (2014), which reports a relationship of income growth and households assets with food security. One of the benefits associated with wealth is the possibility to hire labour and buy equipment. Having labour or equipment available can for example prevent late planting which exposes bare soil to the first torrential rains of the season and late or inefficient weeding (Tittonell, 2014). Therefore, higher wealth could lead to higher productivity, regardless of the used fertilisation method. However, in the linear regression analysis no significant relationship was found between the wealth indicators and yield. All the selected farmers were considered smallholders which possessed a similar amount of land. Possibly, farmers in the region with a better financial situation and therefore investment capacity (also in land) were not part of this research. The effect on wealth and increased investment capacity might have become visible if different farm sizes and wealth groups would have been part of this research.

An integrated PCA was performed to get insight into the main drivers of variance in the dataset and how these relate to the two farm types (Appendix, section 7.2.5, page 45). The two farm groups can be distinguished on the PCA, mainly driven by variation in maize plant health, maize yield and BAZ and some soil characteristics (mainly soilPC2). This corresponds with the significant differences that were found between the conventional and organic farmers for maize plant health, maize yield and BAZ and the findings of the linear regression analysis. Regarding the role of soil nutrients, the PCA suggests that variation soilPC2 plays a role in separating 'successful' farmers (higher yield, higher BAZ) from the less successful farmers.

4.2 Limitations of the study

This study gives a general image of the effect of two different soil amendments on the food security of farmers. Working in a field setting instead of a controlled experimental setting has had the disadvantage that it was not possible to quantify the exact effect of using a certain fertilizer type on yield and soil fertility. There are many other factors that could have influenced the results; the historical farm management, local soil fertility, or time spend on farm management practises like weeding. The farmers trained by ZEFP or SEISUD have learned several farmer techniques next to compost making. Techniques like crop rotation, intercropping or weed management were not included in this study while this could have influenced the soil fertility and crop yields. It was not feasible to include the effect of weeds and pests on the harvest and plant health in the research while this could also have had an influence. Most of the farmers that use mineral fertilizers also used other chemicals like pesticides and herbicides while none of the organic farmers used these chemicals. No information was collected on what type of organic methods farmers have used against pests. In addition, it was not possible to test the quality of the compost nor was the information given by the farmers on the quantity of the compost they applied sufficient to be analyzed. Therefore, the results were not corrected for the quantity of fertilizer the plants received. Most farmers started to apply compost between 4 to 7 years before the start of this research. Furthermore, most farmers only added compost to a certain plot of land once every three years. This is a relatively short period to build up soil fertility, especially when relatively small amounts of organic input are applied.

Due to the limited time and resources available, the BMI method was used to estimate the health of the households. There are many indicators available to assess food security (Vaitla et al., 2017). Possible alternatives include the Food Consumption Score (ODAV-WFP, 2008), the Household Dietary Diversity Score (Swindale and Bilinsky, 2006), Household Hunger Scale (Ballard et al., 2011), the Coping Strategies Index (CSI) (Maxwell et al., 2008). These indices might have given better insight into the degree of food insecurity of the studied farmers. However, food security remains a complex concept that is almost impossible to assess accurately. In the literature, there is a general consensus that there will never be a single measure that can capture food security accurately (Maxwell et al., 2014).

In this study it is assumed that money and food is acquired by family members within the household and consumed and used by families within the household. The social interactions of a household at the societal level are much more complex. In this study the side activities of the family members were also not considered for the analysis. One of the hypotheses was that organic farmers need to invest more labour, time and energy. Unfortunately, due to time constraints, it was impossible to collect enough reliable quantitative information on the investment of time and energy from the farmers on their chosen method. However, based on the conducted interviews it emerged that this is regarded as an essential difference between the two treatments. Specifically, the availability of labour has a large influence on the compost quantity and quality and therefore on the effect of the compost application on the harvest. For future research it would be advisable to include labour in the analysis. The influence of labour availability was not tested in this research. More on the role of labour in the farming system can be found in the appendix (page 38).

4.3 Future perspectives

4.3.1 Future research

Between 2008 and 2017 Ghana has spent 570.8 million GH¢ on mineral fertilizer subsidies, taking up 24 to 49% of the yearly agricultural budgets. The aim of the program is to combat hunger and to enable smallholders and the poorer section of the population to purchase mineral fertilizers. However, smallholders in remote areas ended up profiting less from these subsidies then wealthier, larger farms in more fertile regions (Houssou et al., 2017; Kotschi, 2013). By spending a large portion of the budget on these subsidies, there is limited funds left to spend on promoting other agricultural activities. More research on different agricultural methods could inform decision makers and influence how the funds available for agricultural activities are divided.

A study with a larger sample size could give a clearer image of the effect of the use of different fertilization methods, regardless of the variability present between the different farmers that is unrelated to the fertilization scheme. Other aspects of soil fertility and plant health that were not included in this study could also give more insight on the influence of compost use. Examples of additional measurements that could be included are the soils moisture retention capacity, soil structure, measures for the soil biota (e.g. soil biodiversity, microbial activity), presence of pests and grain quality. Measuring the nutrient composition of the compost is also strongly advised. For research on harvest, it might be advisable to collect data from the field, rather than from the farm where many processes have already occurred, both social (trading, donating, consumption) as practical (post-harvest losses). For future studies, it might be of interest to examine differences in frequently used methods that reflect food production and to identify what causes these differences.

To successfully determine the effect of different approaches of soil management outside of a controlled setting, it is essential to follow farmers for a longer period of time. This could give insight into how the land is managed over the years and the degree of inter-annual variability. To determine how resilient the soil is to variability in climate, data from multiple years would be needed. Furthermore, following farmers throughout the year could give a better insight into the degree of food insecurity and the type of coping mechanisms. Differences in health (e.g. stunting) or wealth as a response to improved production might not yet be present or detectable a few years after the transition to organic practises One of the farmers stated he already applied compost for more than 7 years. Interestingly, the soil of this farmer had nutrient contents varying from high to much higher compared to the other farmers. For future research, it could be interesting to investigate if stronger differences between organic and conventional farms can be found after a longer time of application

In this study, no attention was given to the differences in pest and weed control. None of the organic farmers used herbicides or pesticides while some of the conventional farmers did. It might be of interest to research how and to what extent differences in pest and weed control influence the plant health and harvest. From interviewing the farmers, it stood out that the farmers working with chemical pesticides do not read the packages of the pesticides and do not consider the recommended quantity to be applied. The chemicals are also handled without considering the safety-instruction. The unsafe use of these chemicals could have negative effects on health that cannot be captured by using BMI. There is also little information available on the effect of the chemicals on the ecosystem. For example, some farmers have expressed concerns regarding the reduction of medicinal plants growing in and around their fields. Research should be done to verify if the abundance of these plants is indeed declining and if the use of herbicides is (partly) responsible for this phenomenon.

In this study, a clear distinction between either using compost or using mineral fertilizers was made. Since there was not one group that did not use any fertilizer at all, it is not possible to make any statements on the effect of each treatment on itself. Several farmers were met that used both compost and mineral fertilizers. For future research, it could be interesting to look at the success of these farmers. The Integrated soil fertility management (ISFM) approach promotes the use of both organic inputs and mineral fertilizers to maintain soil fertility. More on this approach can be read in the appendix (page 38).

Lastly, I believe that research should maybe focus on community level instead of household level. It is important to have a good understanding of the culture in the studied area, as where the research was conducted households cannot be regarded as loose components. Households are components functioning in a larger, highly social system. I believe it is not feasible to identify all the interactions of households with their environment. Instead, maybe farm systems should be explored on a different level. An alternative could be to compare overall indicators of food security between communities instead of household levels. Comparing on household level can be complex since there are many (unequal) differences between families like family size, farm size, income of side-activities, the gender of the responsible farmer (man or a woman without support from a husband), family's education etc. Correcting for all these differences is close to impossible and the weight of these differences between households can maybe be reduced when similar communities are compared. If certain communities perform better as a whole then others, it would be of interest to investigate what factors make communities prosper. In this process, I believe it is important to combine qualitative and quantitative information in farm system research. For a proper implementation of different types of knowledge and study fields, interdisciplinary collaboration between different fields (e.g. agriculture, health and nutrition and anthropology) and experts would be essential.

4.3.2 Take-away for training

The NGOs that have trained the farmers in this research (ZEFP and SEISUD) focussed on increasing farm production by providing training in organic practises. I believe that when aiming for food security the focus should not only lie on one method or approach, since social dynamics, production (in quantity and diversity), diet and health are all intercorrelated and all influence a households' food security. Regarding health, including education on alternative ways to deal with pests would be a potential solution to the unsafe handling of chemicals. Furthermore, it might be beneficial to introduce education on diet quality and hygiene as well. Improved hygiene might lead to lower diarrhoeal disease and parasite abundance, possibly helping with reducing disease-related malnutrition (Bain et al., 2013). Women have a vital role in the household, as caregivers and in agricultural production. It is generally accepted that women's' empowerment can, through various pathways, have a range of positive effects, including improvements in agricultural productivity, the child and woman' health status and capital (Bain et al., 2013; Ross et al., 2015; Ruel et al., 2018). Women empowerment is already incorporated in many projects aiming for food security and improved maternal and child nutrition in sub-Saharan Africa and could also be included in the ZEFP and SEISUD projects.

This study suggests training in organic practises could be beneficial to smallholders. However, there might be some obstacles in the training of smallholders. Regarding the use of organic fertilizer or other techniques taught by NGOs, farmers will make a risk assessment whether it is beneficial for them to adopt proposed techniques. It takes time to restore the soil fertility and the application of compost will therefore be beneficial in the long term. When initial input is required (for example capital or labour) the lack of short-term profitability and the risk of not profiting from the technique on the long-term could discourage farmers to adopt proposed technologies (Haggblade et al., 2004). This is especially true when the land is rented and there is uncertainty if the farmer will benefit from attained long-term soil fertility (E Ouédraogo et al., 2001). Identifying the limitations and struggles farmers are facing could help NGOs to propose adequate solutions and training programs. These solutions could include providing tools in the beginning, combining both organic and inorganic fertilization until the farmer is ready to put more energy in either of the methods and having farmers have contact with and learn from farmers that have already adopted the proposed techniques for several years.

5 Conclusion

Organic farms had a significantly higher maize yield per hectare compared to conventional farms: 1846/ha against 1155kg/ha. This seems to indicate that their training in organic farming or their association with an NGO has enabled them to reach higher farm productivity. No significant differences in soil nutrient pools have been observed for any of the farm types. No nutrient depletion of the soil of the organic fields was observed, even though these fields reached higher production and received a soil amendment that is estimated to have a lower nutrient concentration. Next to increased yields, the children from the organic farms also performed better regarding child health. None of the children of the organic farms were underweight, on the contrary of the children of conventional farms (14.9%). However, no differences were found for adults' BMI or child height-for-age. Some correlations were found between health, yield and wealth, but complex relationships may have obscured these effects to some extent. Differences between the two farm types might have been the result of the use of a different soil amendment but could also be the result of other factors that can be associated with the involvement of an NGO. Examples include the influence of being part of a farm group, increased awareness and access to knowledge through the NGO.

The evidence from this study does support the hypothesis that the training of small holder farmers has a positive effect on food security. The results so far have been promising and encouraging to further explore organic farming practises as a means for food security. Given that the findings are based on a limited number of farms, the results should be treated with considerable caution. These findings should be validated with a larger sampling size. The limitations of this study give material for thought for the design of future studies. I suggest that food security should be assessed on community level instead of a household level and advise future researchers an interdisciplinary approach (agriculture, health and nutrition and cultural anthropology) when assessing food security.

The findings of this study might help NGOs to find a course of action when designing training programs for smallholders in Northern Ghana. The high prevalence of stunting found among the children also highlights the importance of interventions to reduce malnutrition in this region. I hope this work will stimulate further research and will help the NGOs that are currently working hard to help farmers to produce sufficient and healthy food based on ecological principles.

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7 Appendix

7.1 Additional information

7.1.1 Labour

Limited labour availability can lead to late planting, exposing bare soil to the first torrential rains of the season and late or inefficient weeding (Tittonell, 2014). Indeed, some of the interviewed farmers indicated they could not always plow the land in the best moment. Most farmers in this study hired a tractor to plow the lands or rented a community member that owns a bullock (Derbile, 2010; Personal observations, 2016). When the time is right for these practises there is often a high demand while there are limited tractors/bullocks available in the region. Therefore, farmers rely on their network, wait for their turn or plow their land by hand. Many organic farmers in this research indicated labour as a drawback for using compost when compared to mineral fertilizers. Indeed, it is believed that there is a higher labour cost for the collection and transportation of organic inputs compared to using mineral fertilizers (Quansah et al., 2001). When organic materials are collected from further away, or if the compost is brought to the fields, there is a need for bullock/donkey carts to facilitate the transportation; while spreading out mineral fertilizers was considered relatively easy. Not all farmers had a donkey wagon to their disposal and are forced to use time and other labour-intensive methods to transport organic materials or compost. Ouédraogo *et al.* (2001) mentions that a lack of capital to buy necessary equipment such as pickaxes, wheelbarrows, and carts can be a constraint in adopting compost technology. In addition, due to the heavy work needed there might be a smaller adoption rate among small households (E Ouédraogo et al., 2001). However, the study done by Fröndt (2018) in the same area indicated that labour was not perceived as a drawback. In this study, farmers stated that the work can be shared with the whole family. The NGO SEISUD uses group formation in the training and prompts farmers to build compost pits together (Fröndt, 2018). The farmers declared that the group members from these farmer groups can also be asked for help for tasks that are too much to handle by one family. Such tasks include digging compost pits or turning the compost. Indeed, farmers who participated in this study also started their own farmer groups, which helped with the digging of their compost pits. Several studies stated that poverty limits the capacity to mobilize labour and that collective action might be a promising avenue (E Ouédraogo et al., 2001; Scherr, 2000).

7.1.2 Integrated soil fertility management

By using organic fertilizer, farmers use inputs from within the system and are therefore cycling their nutrients through their system. Most of the farmers from this research brought the leaves of the peanut plants to the compost pile, which was then used to fertilize the maize or millets fields. You could describe this as a cut-and-carry system, where nutrients are transferred from one place to another. Even though most farmers use crop rotations, some areas of the farm never/rarely get fertilized (generally fields far from the house) and some fields get fertilized on a more regular basis (generally fields close to the house) (Tittonell, 2014). This means nutrients are removed from some fields over a longer span of time. Here, farmers generally grow crops that require less nutrients. However, there might be a long-term effect resulting in a point in time in which barely any crop will still be able to grow on the cut-and-carry fields (Vanlauwe and Giller, 2006). Research has indeed already observed fertility gradients within farms (Chianu et al., 2012). The question that arises then is how long would it take for the soil to be fully exploited, what are the consequences for the farmer and what can be done when this happens? Even though nutrient-cycling is important, to replenish nutrient-depleted soils input from outside the system is needed (Sanchez et al., 1997; Vanlauwe and Giller, 2006). Possibly, the most efficient system would consist of the use of both methods. For example, mineral fertilizers can bring substantial crop yield increases. This can lead to an increase in the root biomass which can result in higher soil organic matter. Secondly, it can lead to more above-ground biomass that can be used as a residue for mulching or can be used for the compost pits (Bationo et al., 1998).

The Integrated soil fertility management (ISFM) approach promotes the use of both organic inputs and mineral fertilizers to maintain soil fertility and, in turn, enough crop production. It acknowledges that neither organic inputs nor mineral fertilizers are available or affordable in sufficient quantities for smallholders. Therefore, it promotes the efficient use of scarce inputs. Secondly, organic and mineral inputs are very different from each other and can therefore not fully substitute each other. For example, dependent on their quality, organic inputs have different nutrient release characteristics (Bedada et al., 2014b; Gentile et al., 2011; Place et al., 2003). Three advantages of using both methods mentioned by Place *et al.* (2003) are; *"1) constraints or nutrient shortages for sufficient crop growth may not be sufficiently alleviated by only using either mineral or organic resources on its own, 2) there might be short term benefits of positive interactions between organic and mineral input and 3) the various roles each of these inputs play in the longer term".* Indeed, west African soils are known to have problems with negative nutrient budgets (Bationo et al., 1998; Chianu et al., 2012). Using both methods could alleviate this negative balance, while only using local organic resources or only mineral fertilizer might not be able to. The same might apply for supplying sufficient concentrations of key limiting nutrients.

There are examples of higher returns on labour when a combination of an organic resource and a mineral resource was combined (Place et al., 2003). However, between the different studies evaluating ISFM, there is a large variation in the type of organic or mineral fertilizer being used. This makes it difficult to generalize the results of these studies. Since the use of compost requires different resources than the use of mineral fertilizer (labour and land versus financial capital) it depends on the situation of the farmer whether using both methods is feasible (Place et al., 2003; Vanlauwe and Giller, 2006). The main constrains discussed have been labour and organic material availability for the use of organic fertilizer, and financial capital for the use of mineral fertilizer. The optimal economic solution will therefore result in a trade-off between the cost and availability of labour and the cost of external inputs and the availability of financial capital (Haggblade et al., 2004). This means, that there is not one solution for every farmer. For training programs, it could be valuable to help farmers optimize their farm management based on the resources they have to their disposal. Furthermore, when farmers value a method based on the outcome (increase in yield, financial profitability) it is important that the increased costs to attain these gains in outputs are taken into consideration as well (Haggblade et al., 2004).

7.2 Additional results

7.2.1 Farm yield

Next to the maize yield/ha that was calculated based on field measurements, harvest was also calculated based on weighing of the harvest. Dependent on the crop and total harvest of the farmer, either the complete harvest or a subset of the harvest was weighed. Crops measured included maize, millet, sorghum, rice, groundnut, soya, yam, pepper, bambara beans, tomato, sweet potato, onion, okra, kama, paprika, watermelon, shea, gardenegg, cowpea, sesam, banana, bira/bito and neri (white-seeded melon).

Every farmer had packaged the maize in bags of the same size. Of these bags, the average weight of a weighed subset of three bags was multiplied by the total number of bags to determine the total yield (*Farm Maize Yield)*. The data of the total yield of maize measured at the farm in bags (*Farm Maize Yield)* was inconsistent with the calculated yield based on the measurements from the field (Figure 10). I decided to only work with the calculated yield. I expected the *Farm Maize Yield* data to be influenced by contact with relatives (donating or receiving bags) or by selling/buying bags. For example, there were farmers that stated they had no maize fields but later showed a few bags of maize yield anyway. Secondly, since the bags were very heavy (around 100kg) we weighed some bags at different farms but could not weigh every bag individually. Some farmers kept their maize in maize cribs. Therefore, we could not weigh the harvest and were dependent on their estimates of the number of bags they had put in the cribs. Lastly, the *Farm Maize Yield* could have been influenced by the post-harvest losses. Since the degree of post-harvest losses is not considered in this it was concluded that it would be better to use the calculated yield.

The data did not have outliers, was normally distributed (Shapiro-Wilk test) and had no significant correlations (Pearson). For none of the variables unequal variance was found (using Levene-test). With the farm yield dataset, no significant differences were found between the mineral or organic farms (t-test, p=0.85).

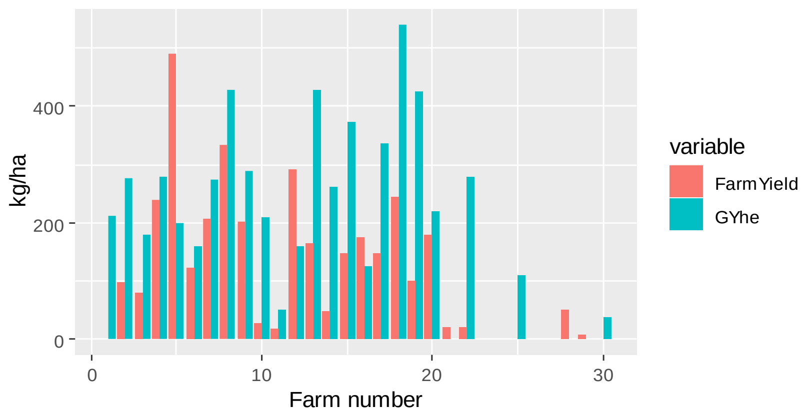

Figure 8. Maize yield in kg/ha for each farm collected with two different methods. FarmYield is the harvest weighed in bags and GYhe is the calculated yield. The calculated yield was based on the average yield of 10 plants corrected for the number of plants/ha and the maize field size.

For crops of which the harvest is piled, like sorghum and millet, the farmer was asked how many head bowls (Figure 9) he/she thought were harvested. Consequently, three head bowls were filled as they would have done on the field to estimate the average weight per bowl. To be able to convert the harvest to a yield/ha the total area of every field was determined using a GPS-tracker (Garmin E Trex 10). For millet it was not possible collect reliable information for every farm.

Figure 9 Weighing of a headbowl of millet.

Since every farmer grew a different combination of crops, there were only a few farmers per crop. The interviews indicate that some crops received little attention from both the organic farmers as the chemical using farmers. Therefore, I suspect that there will be minimal differences between the mineral and organic farmers in the treatment of these crops. Furthermore, it was not always possible to determine the total yield accurately. Part of the harvest was sometimes already sold, eaten or lost in the process of harvesting and storage. These reasons combined made me decide to discard the dataset all together. However, the number of crops grown was used as an indicator of food diversity for the linear regression analysis.

7.2.2 Soil

Table 2. F-statistics and p-values for the comparison between organic and conventional farms per nutrients or soil characteristic. The fields are from conventional (n=8) and organic (n=9) maize fields from farmers in the Northern Region or from conventional (n=4) and organic (n=6) millet fields from farmers in the Upper-East region.

	Northern Region		Upper-East Region	
	F	*p-value*	*F*	*p-value*
OM	0.505	0.490	0.000	0.985
Ntot	0.001	0.981	0.210	0.651
Ptot	0.390	0.543	0.006	0.939
K	0.086	0.775	0.009	0.927
Ca	0.347	0.563	1.084	0.310
Mg	0.353	0.566	0.123	0.729
Na	2.421	0.144	1.444	0.243
NO3	1.200	0.293	1.381	0.253
NH4	0.000	0.999	0.909	0.351
PO4	4.334	0.058	0.768	0.391
pH-H20	2.180	0.164	0.006	0.939
pH-KCl	1.196	0.294	0.000	0.992

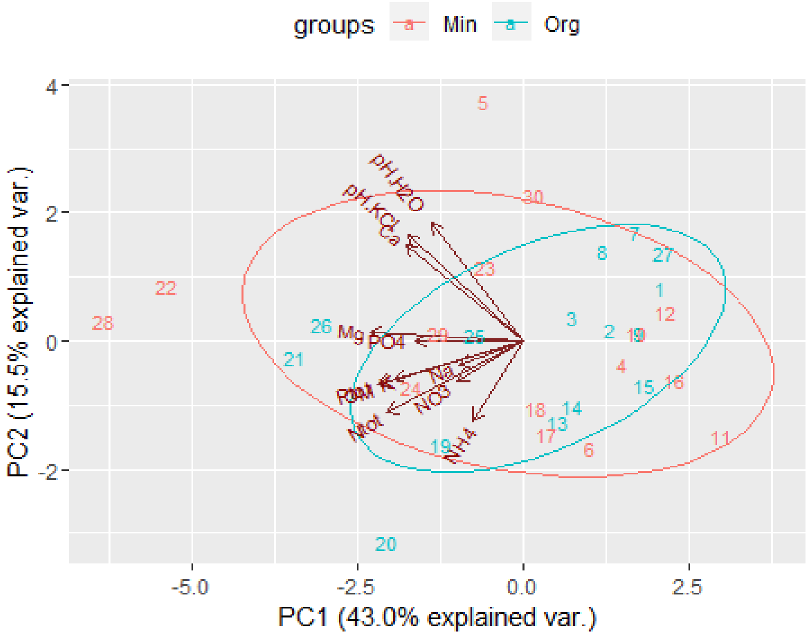

Figure 10 Biplot for the PCA for the soil fertility characteristics (pH.H_2O, pH.KCl, OM, N_{tot}, P_{tot}, PO_4, NO_3 an NH_4, K, Mg, Ca, Na). Based on farmers of the Northern Region (n=17). Conventional farmers are indicated in pink ("Min") and organic farms in blue ("Org").

A PCA was performed for the soil nutrients for the farmers in the Northern Region (Figure 10). All three principal components had a negative to neutral correlation with pH. The variables pH_{H2O}, pH_{KCl}, OM, N_{tot}, P_{tot} and PO_4 contributed most to the first component (soilPC1), between 11 and 15% each (Table 3). SoilPC1 was positively correlated with OM, Ntot and Ptot and negatively correlated with PO_4. The variables pH_{KCl}, Ptot, Ca, Mg and Na contributed most (between 10 and 16% each) to the second component (soilPC2). SoilPC2 was negatively correlated with Ca, Mg and P_{tot} and positively correlated with Na. The variables K, Mg, NO_3 and PO_4 (26,24,12 and 13% respectively) contributed most to soilPC3 with K and Mg being negatively correlated and NO_3 and PO_4 being positively correlated (Table 3).

Table 3 Contributions of soil fertility characteristics to the principal components to the PCA and correlations of the soil fertility characteristics with the principal components.

	Contribution to principal component (%)				Correlation with principal component (Spearman's rho)		
	PC1	**PC2**	**PC3**		**PC1**	**PC2**	**PC3**
OM	**14.99**	7.07	0.49	**OM**	**0.76**	**-0.42**	**0.11**
Ntot	**15.44**	2.76	4.80	**Ntot**	**0.78**	**-0.26**	**0.33**
Ptot	**13.75**	**10.20**	0.72	**Ptot**	**0.73**	**-0.51**	**-0.13**
K	3.73	0.01	**25.70**	**K**	**0.38**	**0.01**	**-0.76**
Ca	5.56	**16.34**	5.21	**Ca**	**-0.47**	**-0.64**	**-0.34**
Mg	0.38	**14.49**	**24.08**	**Mg**	**-0.12**	**-0.60**	**-0.74**
Na	1.23	**12.89**	5.37	**Na**	**0.22**	**0.57**	**-0.35**
NO3	7.52	8.69	**11.54**	**NO3**	**0.54**	**-0.47**	**0.51**
NH4	0.06	7.93	8.77	**NH4**	**-0.05**	**-0.45**	**0.44**
PO4	**12.86**	0.14	**12.84**	**PO4**	**-0.71**	**0.06**	**0.54**
pH.H2O	**11.77**	5.66	0.25	**pH.H2O**	**-0.68**	**-0.38**	**0.07**
pH.KCl	**12.72**	**13.83**	0.23	**pH.KCl**	**-0.71**	**-0.59**	**-0.07**

7.2.3 Plant health

Table 4 t-statistics for plant characteristics between farmers in the Northern Region using mineral fertilizers (conventional farms, n=8) or organic fertilizers (organic farms, n=9).

Plant characteristic	**t-statistics**	**p**	
Plant height	t_{13}=-1.74	0.106	
Leaf length	t_{15}= 2.77	0.014	*
Leaf width	t_{13}= 2.53	0.026	*
Number of leaves	t_{13}= 2.51	0.025	*
Number of grains	t_{13}= 1.89	0.081	
Fresh weight ear	t_{15}= 3.36	0.004	**
Dry weight grains	t_{13}= 2.91	0.012	*

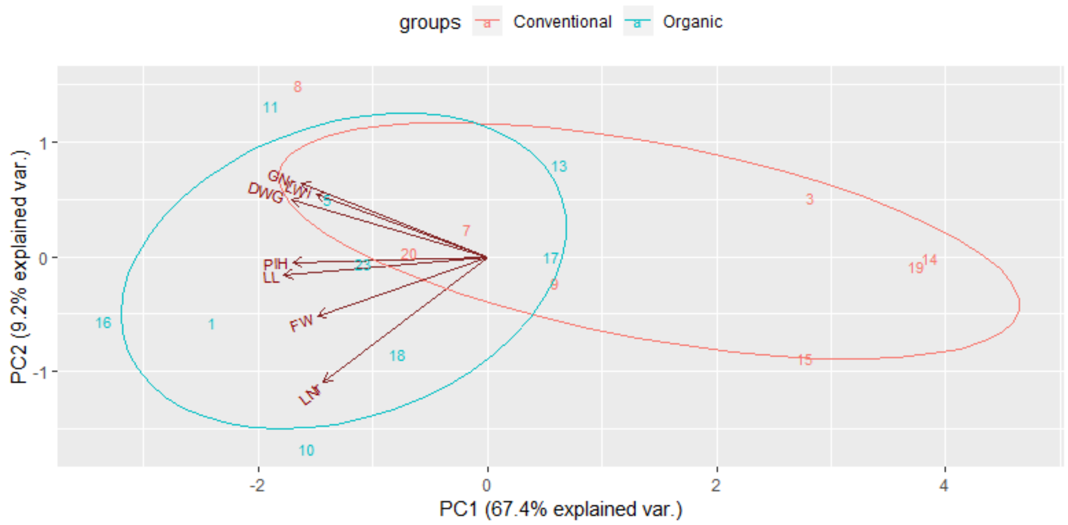

Figure 11 Biplot for the PCA for plant health characteristics for the organic and conventional farmers in the Northern Region (n=17). Conventional farmers are indicated in pink (“Min”) and organic farms in blue (“Org”).

Table 5 Eigenvalues and % of variance explained by plantPC1 based on the plant PCA (Figure 11) and contributions of plant health characteristics to the principal component.

	Plant PC1
Eigenvalue	2.17
Variance (%)	0.67
Cumulative Variance	0.67
	Contribution of variables
Plant height	15.97
Leaf number	11.32
Leaf length	17.42
Leaf width	12.36
Fresh weight ear	12.19
Grain number	15.67
Dry weight grains	16.06

7.2.4 Wealth

To get insight into whether there were farm types present among the farmers based on resources instead of on the treatment, a hybrid hierarchical k-means clustering was performed. The classification was based on the capital farmers invested in seven categories, based on value and function (Table 6). The clustering resulted in a division where farmers with a lower total capital investment were grouped together and farmers with a higher capital grouped together (Figure 12). Based on this it was assumed that for this study the total capital invested would be a suitable indicator for wealth and that there were based on resources, no other clear farm types present.

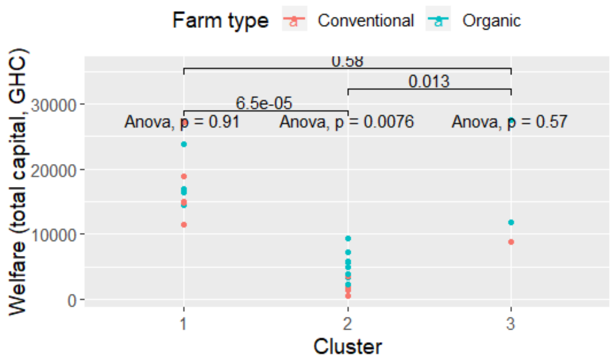

Figure 12. Farm type clusters based on invested capital in several categories plotted against total invested capital.

Table 6 Categories used for classification of farmers based on capital invested in animals and objects.

Category	**Value**	**Included**
Small animals	25-70	Chicken, Rabbit, Duck, Guiniefowl, Turkey
Medium animals	250-300	Goat, Pig, Sheep
Big animals	600-1400	Donkey, Donkey wagon, Cow
Small objects	15-40	Hoe, Shovel, Machetes, Chair, Table
Medium objects	130-250	Phone, Wheelbarrow, Bike
Luxury objects	160-900	Fan, Smartphone, Matrass, Television
Expensive objects	1500-6650	Fridge, Scooter, Motor

7.2.5 Methods and results for the PCA analysis for food production, health and wealth

A principal component analysis (PCA) was performed to explore the trends and correlation structure between the three studied aspects (Figure 1) and to explore which variables differentiate organic farms from conventional farms. The final PCA was made for the three aspects; food production (soilPC1-3, maize plant health and grain yield), health (adults: BMI, children: BAZ and HAZ) and financial situation (invested capital in animals and objects). For the mixed modelling approach health was corrected for confounders like age, sex, family size, village. This was not possible for the principal component analysis where the averages of BMI, BAZ and HAZ were used to reflect the health status of the family. To give an image of the difference in variation between the groups, I assumed for this analysis that the averages would function well enough to serve as an indicator. Differences in for example age classes, family size and gender representations could have influenced or distorted the results of the PCA. Therefore, the results of the PCA should be interpreted with caution. The PCA was based on 16 farmers ($n_{organic}$=8, $n_{conventional}$=8) due to some missing values and due to the data for maize (maize plant health and maize yield) being only available for farmers from the Northern Region.

Four principal components were found with an eigenvalue greater than 1, explaining 78% of the variation. Based on the scree plot and the eigenvalues, only the first two principal components will be discussed (explaining 33% and 20% respectively). For the first principal component the highest contributors were maize yield, soilPC2, plantPC1, BAZ and HAZ. For the second principal component soilPC1, soilPC3, plantPC1, BMI adults and HAZ (Table 7).

Table 7 Contribution of parameters to PCA-components/dimensions in %. Values are displayed in blue when the contribution of values was larger than 10%.

	PC1	PC2	PC3	PC4
Eigenvalue	1.73	1.34	1.08	1.06
Variance (%)	33.1	19.93	12.93	12.46
Cumulative Variance	33.1	53.03	65.97	78.43
	Contribution of variables			
Maize yield	**23.66**	1.55	2.12	0.10
soilPC1	1.98	**26.08**	0.31	0.08
soilPC2	**16.68**	4.63	5.87	6.53
soilPC3	0.17	**13.16**	**15.40**	**34.07**
plantPC1	**20.81**	**13.21**	0.95	0.01
Welfare	0.17	2.40	**69.16**	6.36
BMI	0.65	**13.68**	3.43	**44.82**
zbfa	**20.90**	0.37	2.74	5.40
zhfa	**14.99**	**24.93**	0.03	2.62

The PCA suggests that the two farm groups differ from each other (Figure 13). On the first component, there were more occurrences of conventional farms with lower maize plant health, lower maize yield and low BAZ which is in accordance with the previous presented results. These farms also display higher values of soilPC2. SoilPC2 was negatively correlated with Ca, Mg, Ptot and pH and positively correlated with Na. Indeed, the farm with the lowest value for the first component (PC1=-2.97) displayed the lowest Ca, Mg and Ptot concentrations and the lowest pH of all farms and was also on the lower end of the productivity spectrum. Interestingly, the farm with the highest score for the first principal component (PC1=3.14), in the upper-right spectrum of the PCA, had the highest values for BMI, BAZ HAZ, the highest value for plantPC1, soilPC1 and maize yield.

For the second component both groups contained farmers that had higher values on the second principal component. These farmers had higher values for BMI for adults, wealth, HAZ and soilPC1. SoilPC1 was positively correlated with OM, Ntot and Ptot. Therefore, farmers scoring low on the second principal component can be associated with lower OM, Ntot and Ptot concentrations. There were more occurrences of organic farms in the lower spectrum of the second principal component. These farmers also had higher values for soilPC3 indicating low K and Mg concentrations and higher PO4 and NO3 concentrations.

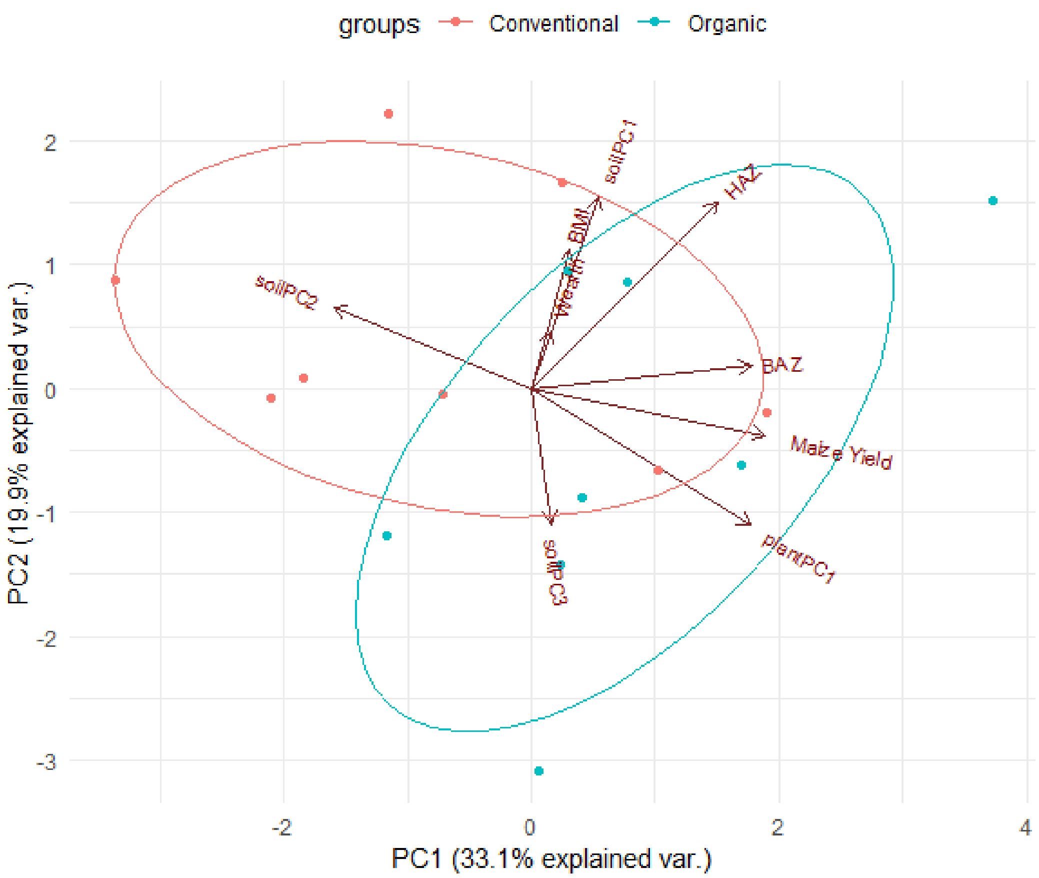

Figure 13. PCA for all the researched aspects. The PCA is based on 16 farmers from the Northern Region ($n_{organic}$=8, $n_{conventional}$=8).

7.3 Interviews

7.3.1 Expenses

How many wives do you have?
How many children do you have? How many children go to school?
To which school do they go? Do you know the school fee?
Do you have other family members that are important for the expenses?
What other big expenses did you have this year? (hospital etc.)
How do you afford these big expenses? (bank/mobile-money/selling animals)
Do you give money to your wife/husband for ingredients etc? (If so: how much per week/month?)
How much money do you think the family spends on bought ingredients?
Do you get money from family members?

7.3.2 Income

How do you earn money? How much does that give?
Are family-members generating income? (wives, husband etc.) How?
Do you suffer food insecurity?
Which of these crops do you grow?
What is the profit you make of selling crops? Which crops?

7.3.3 Possessions

7.3.3.1 Objects

Which of these objects do you have? (Picture chart)
What is the material of the walls?
What is the material of the roof?
What material do you use for cooking? (Firewood, gas etc)
Do you have electricity? (If so, how much does that cost?)
How do you get water? How much does that cost?
How many sets of clothes do you have?

7.3.3.2 Animals

Which of these animals do you have?
Have you eaten some of your own animals this year?
How many animals have you sold this year?

7.3.4 Management

7.3.4.1 Organic

Do you use mineral fertilizers anywhere?
In which year did you apply compost for the first time?
What did you do before that?
Can you explain me how you make the compost?
Do you bring the residuals from the field back to the pit?
Of which animals do you collect the manure for the compost?

In which month do you start making your compost?

Which crops do you normally fertilize? When?
How much do you apply?
How often are the most important fields fertilized?
Do you use crop rotations?

Do you hire extra labour? For what? How much does that cost?
Do you do weeding? How many times for which crops?
Do you do ploughing? How much does that cost?
Is your farm burned? (Forest-fire, poachers, own management)
Do you ever think about buying mineral fertilizers?

7.3.4.2 Chemical

Did you ever try using compost? If so, when and where?

What type of chemical fertilizer do you use? (NPK e.d.)
What is the brand of the fertilizer you use?
How much fertilizer did you buy this year?
What is the price (per kg)?
How do you get the money for the fertilizer? Credit/Loan?

In which month do you apply the fertilizer?
Do you apply every year? Or in parts?
How much do you apply where?
Which crops do you normally fertilize?

Do you hire extra labour? (and how do you afford this)
Do you do weeding? How many times for which crops?
Do you do ploughing? What does this cost you?
Is your farm burned? (Forest-fire, poachers, own management)
Is your farm burned? (Forest-fire, poachers, own management)

Do you use other chemicals like pesticides/weedicides?
What is the brand?
What do they cost?
How much did you buy?

Do you ever think about going organic?