Ecosystem-based interventions and farm household welfare in degraded areas: Comparative evidence from Ethiopia

ABSTRACT

Agricultural productivity and farm household welfare in areas of severe land degradation can be improved through ecosystem-based interventions. Decisions on the possible types of practices and investments can be informed using evidence of potential benefits. Using farm household data together with a farm level stochastic simulation model provides an initial quantification of farm income and nutrition outcomes that can be generated over a five year period from manure and compost based organic amendment of crop lands. Simulated results show positive income and nutrition impacts. Mean farm income increases by 13% over the planning period, from US$32,833 under the business as usual situation (application of 50 kg DAP and 25 kg urea ha^{-1} yr^{-1}) to US$37,172 under application of 10 t ha^{-1} yr^{-1} farm yard manure during the first three years and 5 t ha^{-1} yr^{-1} during the last two years. As a result of organic soil amendment, there is an associated increase in the available calorie, protein, fat, calcium, and iron per adult equivalent, giving the improvement in farm household nutrition. The evidence is substantive enough to suggest the promotion and adoption at scale, in degraded ecosystems, of low cost organic soil amendment practices to improve agricultural productivity and subsequent changes in farm household welfare.

Keywords: farm income; FARMSIM; Halaba special *woreda*; nutrition; organic soil amendment

1. Introduction

The contribution of agriculture to food security and poverty reduction heavily depends on soil quality and ecosystem services (Powlson et al., 2011; IFAD, 2013; McBratney et al., 2014; FAO, 2015). Nevertheless, continuous land use change and poor land management have severely reduced the soil quality in many of the world's managed agroecosystems, with dire consequences on ecosystem services necessary to support agricultural production (Schulte et al., 2014). Degraded ecosystems, particularly in sub-Saharan Africa, provide a typical situation where farming communities are forced to live on marginal benefits, amplified as a result of poor soil functions and low agricultural productivity (Barbier, 2000; Stringer et al., 2012). How to improve soil quality and restore ecosystem services is a key area of research for natural resource management in relation to agricultural productivity and food security in degraded areas.

Improving agricultural productivity and food security in degraded ecosystems requires interventions that reduce soil loss and nutrient depletion to enhance soil functions and ecosystem services (Schwartz, 2014; Daw et al., 2011; Lal, 2011; Mekuria et al., 2013, 2014; Fisher et al., 2014). In Ethiopia, physical soil and water conservation structures to reduce soil erosion and nutrient depletion as a management intervention to enhance agricultural productivity and food security have been implemented since the 1980s (Holden et al., 2001; Beshah, 2003; Nedassa et al., 2011; Zeleke et al., 2014). Though the practices have been effective in reducing soil erosion and nutrient losses (e.g., Oicha et al., 2010), findings with regard to their yield impacts and economic feasibility are mixed (Adgo et al., 2012; Teshome et al., 2013). Nyssen et al. (2007) reported increases in crop yield following the implementation of soil and water conservation measures in Northern Ethiopia whereas Adimassu et al. (2014) and Kassie et al. (2011) reported a reduction in crop yield in the central and north-western highlands of the country.

Changing agricultural crop land use to pasture lands and implementing exclosure management to enhance soil organic carbon and soil functions can be appropriate interventions to increase agricultural productivity. However, in areas where land scarcity limits the possibility for pasture land and exclosure management, (as is the case in most agricultural lands cultivated and managed by small-scale farmers), a far greater potential comes from implementing low cost organic soil amendment practices on crop lands (Bremen et al., 2001; Sanderman et al., 2010; Chivenge et al., 2011; Mekuria et al., 2013, 2014; Poeplau and Don, 2015). Yet, the most appropriate amendment practices to enhance soil carbon and improve soil properties vary spatially depending on both environmental, biophysical, and socioeconomic factors (Mekuria et al., 2014). Case studies conducted in the Ethiopian rift valley (e.g., Ayalew, 2011) and elsewhere in the world (e.g., Mekuria et al., 2014; Poeplau and Don, 2015) show the positive impact of combined compost and inorganic fertilizer application on soil properties and crop yield. Despite this, empirical evidence on farm household income and nutrition impacts of soil-based interventions in degraded areas are scarce (Stringer et al., 2012; Te Pas and Rees, 2014).

Halaba in the Central Rift Valley of Ethiopia had experienced a major land cover change and land use transformation over the last quarter of the twentieth century (Wagesho, 2014). Deforestation and conversion of pasture lands into crop lands have been rampant as a result of growing human population and increasing demand for farm land. Rainfall infiltration through degraded soils has been reduced and surface runoff has increased progressively as a result of exhaustive land use and extensive land cover changes especially since the 1970s. Consequently, soil erosion and nutrient loss as important forms of ecological degradation have undermined agricultural production and system sustainability, with agricultural livelihoods becoming increasingly vulnerable to shocks (Tsegaye and Bekele, 2010). The problem is partly exacerbated by land tenure insecurity (Dercon and Ayalew, 2007).

The low organic matter content of agricultural soils in the Central Rift Valley of Ethiopia makes organic soil amendment a potentially useful intervention to restore soil carbon and enhance soil-based ecosystem services (Abera and Wolde-Meskel, 2013). However, the potential socio-economic impacts of such practices have not been systematically investigated to inform adoption and investment decisions. By considering the case of selected agriculturally based farm households in Halaba special *woreda* (Central Rift Valley, Ethiopia), this paper generates data and evidence to understand whether applying farm yard manure (FYM) and compost[1] as organic soil amendments are appropriate in degraded agricultural lands. The work has been undertaken in the context of agricultural lands cultivated by subsistence farmers and the potential to improve farm household welfare through improved soil management which in turn will positively impact farm income and nutrition. Further to the economic impact assessment of soil amendments, the analysis also considers the role of the livestock, commonly overlooked by similar studies in the field. The study applies a stochastic simulation technique on observed and experimental farm level socio-economic data.

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[1] Compost is an organic fertilizer prepared by decomposing leaves, food scraps, and other organic household wastes. Manure comprises undecomposed feces from livestock such as cattle, equines, and chicken. Fresh manure can be combined with other materials to prepare compost. Though both compost and manure are good sources of organic matter for soils, manure is considered to have a high nitrogen content for better plant growth. However, manure has disadvantage in that it potentially spreads weeds (through undecomposed seeds) and transmits plant disease.

2. Methodology

2.1 The study area

The study was conducted in Halaba special *woreda* (78° 17'N latitude and 38° 06'E longitude), Central Rift Valley, Ethiopia (Figure 1). Average annual rainfall in the area is in the range 857 to 1,085 mm yr^{-1} occurring in a distinct bimodal, seasonal, pattern. Annual temperature varies from 17 to 25^{o}c. The dominant soil type is andosol, with physical and chemical properties depending on land use, land cover and associated management practices. About 70% of the total land area is suitable for agriculture, the main economic activity in the area. The major crops cultivated include maize, teff, sorghum, haricot bean, millet and pepper. Conventional tillage, crop rotation and intercropping are the most common farming and land management practices. Crop production is often mixed with livestock production. The two sub-sectors compete for resources such as land and labor while they complement each other, in so much as the crop sub-sector provides crop residue as livestock feed and the livestock sub-sector provides FYM to improve soil fertility and crop production.

Figure 1. [HERE]

Crop yields in Halaba special *woreda* are below the national average (which in turn is low in comparison to many other countries). According to data collected from sample farm households, average yield per hectare during the 2014/15 production year was 1.99 t ha^{-1} for maize, 1.3 t ha^{-1} for sorghum and 1.4 t ha^{-1} for wheat while the national average was 3.5, 2.5, and 2.7 t ha^{-}1 for maize, sorghum, and wheat, respectively (CSA, 2014).[2] Challenges of ecosystem degradation, low agricultural productivity, and livelihood vulnerability have led a significant number of farm households to abject poverty and food insecurity. The magnitude of the problem has resulted in targeted government intervention through a Productive Safety Net Program (PSNP). The PSNP sets out to protect household assets and improve livelihood resilience while rehabilitating natural resources in degradation hotspots through public work programs for cash payment (MoARD, 2006).

2.2 Data and analysis

The potential poverty reduction and food security impacts of alternative farm level organic soil amendment practices considered in this paper are assessed using a farm level simulation model (FARMSIM) (Richardson et al., 2008). The model uses randomly generated values[3] of stochastic explanatory variables such as crop and livestock yield, cost, and output price forecasted over a five-year planning period and recursively simulates (through 500 iterations) farm income and nutrient level as key outcome variables (Figure 2). Crop and livestock price levels under alternative scenarios can be kept constant to be able to attribute differences in simulated farm income to changes in different management practices. The simulations can be made at an individual (household) or aggregate (village) level. Simulated results can be used to inform farm decision making and risk management by providing quantitative and comparative information about the magnitude and distribution of farm income and nutrition level. These serve as indicators of potential impacts from implementing alternative soil management technologies and interventions in degraded areas. Farm income and nutrition

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[2] The CSA figures are for the 2013/14 production year.

[3] Initial values of stochastic variable are often taken from historical or survey data.

levels simulated by the model can be analyzed graphically to visualize their probability distributions and associated risk levels.

Figure 2. [HERE]

FARMSIM integrates crop, livestock, nutrition and financial model components which endogenously interact to exchange and update data used in the simulation exercise. The financial model calculates net present value of combined net worth, family living expenses, and value of crop and livestock products consumed by farm households as farm income proxy (1). In addition to net farm income (the difference between farm revenue and costs), net present value calculation uses information from annual farm cash flow and balance sheet statements. Family withdrawals and value of crops and livestock products used for family consumption are added to beginning and ending net worth as:

$$\mathrm{NPV} = \mathrm{BNW} + \sum_{i=1}^{5} (\mathrm{FW}_i + \mathrm{CLF}_i) + \mathrm{ENW} \tag{1}$$

where NPV is net present value, BNW is beginning net worth (i.e., net worth at the beginning of the planning period), FW is present value of financial withdrawal for family consumption (cash expense for family living and school), CLF is present value of crop and livestock products consumed by farm households, i (i = 1, …, 5) is the planning period, and ENW is present value of ending net worth (i.e., net worth at the end of the planning period). Ending net worth (2) is calculated using data on cash and non-cash assets and liabilities as:

$$\mathrm{ENW} = \mathrm{CB} + \mathrm{NCA} - \mathrm{LB} \tag{2}$$

where CB is cash balance (i.e., difference between total cash inflow and total cash outflow), NCA is non-cash asset (such as land, machinery, tools, and livestock) and LB is liability or loan.

As applied in this paper, the model uses the above financial information to simulate net present value obtainable under alternative management practices implemented to restore soil carbon. Soil management practices to increase soil carbon are expected to improve crop yield and livestock production through which increase food consumption and financial benefits of farm households are made possible. Therefore, information generated on the level and distribution of simulated net present value can be used as proxy to assess farm level poverty impacts of soil carbon restoration practices.

The nutrition model of FARMSIM simulates nutrition level that a farm household can secure from different food sources (own crop and livestock products under alternative management practices, food purchase, and food aid). The model uses information on type and quantity of crop and livestock products consumed by farm households and on respective nutrition levels of each crop and livestock product type. Total kilocalories, protein, fat, calcium, iron and vitamin A that a farm household can secure are calculated as product of the total amount of crop consumed by a family from different food sources. These in turn are used to compute the respective nutrient level obtainable from each crop type. Nutrients derived from consuming beef, milk, butter, chickens, eggs, mutton, lamb and goat meat are simulated using a similar procedure. The total nutrients consumed by a farm household from all food sources is therefore simulated by summing the obtainable nutrient levels across all crop and animal food types eaten. The minimum daily nutritional requirements per adult equivalent set in the model are 1,750 kilocalories, 41.25 grams protein, 39 grams fat, one gram calcium, 0.009 grams iron and 0.6 grams Vitamin A (UN-FAO, 2011). Nutrient adequacy is evaluated by considering the quantity of obtainable nutrient level per adult equivalent. Assuming equal food distribution among family members, a per capita obtainable nutrient level exceeding or equal to the minimum daily requirement for each nutrient type ensures nutrition adequacy and security.

2.3 Soil management practices

Soil management practices considered in the simulation exercise are characterized as business as usual situation (baseline scenario) and combined FYM and compost application (alternative management scenarios).

The baseline scenario

Agricultural production in Halaba special *woreda* under the business as usual situation is characterized by a low input and low output crop-livestock mixed farming system. Agricultural productivity is heavily constrained by problems related to population growth and natural resource degradation. Though farmers use chemical fertilizers (DAP and urea) to improve soil fertility, fertilizer use is often below the recommended rate and is limited only to the production of major cereals such as teff, wheat and maize. For example, though about 13% of teff and wheat producers used the recommended rate of 100 kg DAP ha^{-1} during the 2008/09 production year, the majority (about 61%) applied DAP only at a rate of 16 to 50 kg ha^{-1} (Urgessa, 2011). The average application rate of DAP for teff and wheat production was about 55 kg and 81 kg ha^{-1}, respectively. Since crop residues are often used as livestock feed and as fuel wood, nutrient removal from farm lands is considerable, with the subsequent detrimental effect on soil fertility, soil functions, and crop yield (Haileselassie, 2005). Crops are primarily used for family consumption and income generation purposes, with only a limited proportion saved for seed and negligible amounts for livestock feed.

Livestock production is limited to cattle, sheep, goat, and chicken production as farm assets, as additional sources of farm income, and also as sources of protein food (milk, butter and, sometimes, meat) for farm households. Farm income and food consumption are closely determined by farm level crop and livestock production, with supplements from purchased food, international food aid, and (in the case of a few farm households) remittance. Table 1 summarizes the basic information collected on sample farm households and their production activities as observed under the baseline situation.

Table 1. [HERE]

Alternative management practices

Manure application is considered as one of the most effective practices to improve tropical soil quality (Kihanda et al., 2004). Manure application to soils helps to increase crop yield by improving nutrient availability (such as nitrogen, phosphorous, and potassium) and the water retention capacity of soils. It also improves other soil properties essential for plant growth, such as mineralization-immobilization patterns and it serves as an energy source for microbial activities and as precursor to soil organic matter (Kihanda et al., 2004).

Manure can be supplemented with inorganic fertilizers to top-up the nutritional requirements of plants (Kihanda et al., 2004; Agegnehu et al., 2014). The application of inorganic fertilizers in crop production (the dominant practice under the business as usual situation in the study area) could be replaced by the combined application of inorganic fertilizer and FYM or compost to further improve soil fertility and crop yield. Accordingly, except under the baseline scenario case in which farmers apply only inorganic fertilizers, alternative organic soil amendment practices assessed in this paper consider combined application of organic and inorganic fertilizers on crop lands (Table 2).

Table 2. [HERE]

The actual quantity of FYM and compost required for organic soil amendment depends on the initial soil organic matter content and whether farmers are already use inorganic fertilizers as nitrogen sources. Continuous and high application rates of manure and compost might not necessarily lead to yield increase if the nitrogen requirement of the soils is already satisfied. This could occur either because of excess nitrogen quantity, residual effects from previous applications or because of the use of adequate inorganic fertilizers as nitrogen sources. For this study, it is suggested as reasonable to limit the applications to 5 t ha^{-1} yr^{-1} and 10 t ha^{-1} y^{-1} for each the FYM and compost based treatments (Table 2). This is supported by considering the continuous application of inorganic fertilizers by farmers (though below the recommended rate); the limited quantity of FYM and compost that farmers can apply; and the high labor cost (including that of family labor) incurred in the preparation and field application of such materials.

2.4 Data

The data used in the analysis were collected through farm household survey conducted in three selected sites (Figure 2) with regard to crop and livestock production and market dynamics for the baseline situation by considering 2014/15 as base year. The 2014/15 survey data on crop yields are subjected to certain yield growth assumptions (based on available literature) to determine crop yield that could be observed during the 2014/15 production period under each alternative management practice. Farmers are assumed to implement alternative organic amendment practices by applying different combinations of compost and FYM on crop lands of maize, teff, wheat, sorghum, onion, field peas, millet, and pepper as the most commonly cultivated crops in the area.

Crop and nutrition data and yield assumptions

The data set used in the crop model includes observations on farm input quantity, input cost, crop yield, and output price as reported by farm households. The data were collected across 18 sample farm households[4] in three sites (Arsho, Choroko, and Asore – Figure 2) in June 2014 using survey questionnaires to define the baseline situation of crop production, financial flow and farm household nutrition (Table 1). Data collected for the nutrition model include the quantity of food procured from outside sources (food purchased and food aid) for farm household consumption to supplement own production. Potential farm income and nutrition impacts of the alternative organic soil amendment practices have been simulated by considering the case of the 18 sample farm households who altogether cultivate 49 ha under the different crops considered and had an adult equivalent family size of 122. Farm households were selected based on the fact they implemented FYM and compost on their teff crop during the 2014/15 production year, under experimental trial intervention program. The experiment tested crop yield and soil property impacts of FYM, compost, inorganic fertilizer, and combined FYM, compost and inorganic fertilizer application.

Crop yields for the first year (2014/15) of the planning period under the baseline situation are averages of crop yields observed for the 18 experimental farm households. Expected crop yields increase from implementing alternative management practice varies between 7.5 and 15% (Table 2). The assumptions on such variations are based on empirical evidence from the relevant literature with regard to obtainable yield levels under similar management practices (e.g., Ghosh et al., 2004; Dong et al., 2006; Ding et al., 2012). For example, according to Ghosh et al. (2004) and Ding et al. (2012), there is a 9.5% increase in cereal yield, on average, as a result of combined

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[4] Most decision makers have limited data for decision making. FARMSIM uses algorithms to define probabilistic distributions of exogenous and decision variables from small sample data or limited observations.

application of inorganic fertilizers with 5 to 10 t ha^{-1} yr^{-1} manure. This figure can increase to 13.5% if manure application rate exceeds 10 t ha^{-1} (Ding et al. 2012, Dong et al. 2006). According to Ghosh et al. (2004) and Ding et al. (2012), average yield increases of pulses due to 5 to 10 t ha^{-1} yr^{-1} manure application in combination with inorganic fertilizers is about 14%. This figure can shift to 13.5% for application of more than 10 t ha^{-1} manure (Ding et al., 2012; Dong et al., 2006). Kihanda et al. (2004) shows that organic amendments result in significant annual yield increase mainly during the earlier years. However, Eghball et al. (2004) suggests that high rate application of organic amendments in later years may not necessarily impact any significant extra yield during which soil organic matter improves as a result of sufficient nitrogen accumulated from continuous applications during the early years. Accordingly, we considered a reduced compost and FYM application rate scenario (from 10 to 5 t ha^{-1} yr^{-1}) for management alternatives A3 and A5 (Table 2).

Crop yield data for the rest of the planning period (2015/16 to 2018/19) under each management alternative are assumed to be similar to the respective yield data considered for the 2014/15 production period. Stochastic crop yield levels used in simulating respective farm income and nutrition levels are thus generated from such crop yield levels assumed to hold true for the entire planning period (2014/15 to 2018/19) under each management alternative.

Livestock data and yield assumptions

Livestock data were collected on the number of livestock (cattle, sheep, goats, and chickens), herd dynamics (death, birth, family consumption, and purchase) and quantity of milk, meat, eggs, and manure produced by age cohorts. Since the simulation exercise captures the link between the crop and the livestock sub-sectors, the data set also includes data on grain used as livestock feed. The crop-livestock mixed farming system in the study area is characterized by interactions between the crop and the livestock. Therefore, improved crop productivity as a result of implementing alternative organic soil amendments is likely to increase crop residue available as livestock feed. Subsequently, milk and meat production, cattle weight, manure production, and fertility increases, and death rate declines.

The farm income and nutrient level simulation exercise incorporates only the impact of expected crop yield growth under the alternative management practices on milk yield. This was done as it was difficult to quantify and model the impacts of the amendment practices on the remaining livestock variables such as reproduction rate and death rate. The impact of organic soil amendments on milk yield is approached by first estimating the obtainable quantity of crop residue from each crop type under each management practice. This was followed by assessing the respective impacts of estimated crop residue quantities on daily milk yield. The additional crop residues were estimated by using rates similar to those used to estimate grain yield growth (Table 2) under the assumption of a fixed crop harvest index for each crop type. Accordingly, a 7.5% growth in crop yield under management alternative A2 is assumed to contribute to a 7.5% growth in crop residue.

According to NRC (2001), average milk yield (kg) of cows from consuming one kilogram wheat, teff, and maize stover is 0.1 kg, 0.22 kg, and 0.32 kg, respectively. Assuming farm households sell a considerable proportion of additional crop residues for cash income generation purposes, there is only 10% of the additional crop residue that can be associated with additional milk obtainable by farm households under the alternative organic soil amendments. Accordingly, milk production is assumed to increase by 77%, 129%, 103% and 154% due to the implementation of management alternative A2, A3, A4, and A5, respectively. These figures were reached at by calculating first the volume of obtainable additional milk as product of the fraction of added dry matter (for each crop type as a result of yield growth from the respective treatments) and the average milk gain per cow per year per kilogram of added dry matter (NRC, 2001). Then, the ratio of additional milk volume to that of the baseline period's milk volume is calculated for each crop type and multiplied by 100 to estimate growth rate in milk production in percentage terms. Finally, average growth rate of milk production under each scenario is estimated using growth rates calculated for each crop.

Production costs and assumptions

Farm income and nutrition outcomes of farm households from implementing alternative management practices are expected to vary as a result of differences in terms of yield outcomes and material and labor costs incurred in FYM and compost preparation and application. Information obtained from the study area show that farmers incur additional US$25 as labor cost to apply 5 t FYM ha^{-1} and US$102 as labor and material cost to prepare and apply 5 t compost ha^{-1}. Accordingly, labor and material cost incurred for management alternative A2, A3, A4, and A5 (Table 2) is estimated at 125, 249, 502, and 804 US$ ha^{-1} yr^{-1}, respectively.

2.5 Sensitivity analysis

Obtainable farm income and nutrient levels from alternative land management practices are sensitive to changes in the values of underlying variables, such as yield, cost, product consumed (and marketed), and discount rate applied, among others. The implication of yield growth and cost reduction on farm income and nutrient level is straightforward. Other things held constant, yield growth and cost reduction improve farm income and nutrient level and *vice-versa*.

Farm income (net present value) obtainable under alternative organic soil amendment practices is subject to discount rate applied on future cash flows. Applying a high discount rate significantly reduces net present value and *vice-versa*. Farm income under each management alternative is simulated using a 10% discount rate. The impact of a 5% increase and decrease in the initial discount rate (10%) and that of a 5% reduction in respective output prices was tested to account for economic uncertainty related to implementing the alternative land management practices. Furthermore, the sensitivity of respective mean simulated farm incomes was tested using 15% and 5% discount rates. A 15% discount rate was applied to account for various risk factors that farmers might face in implementing the respective organic soil amendments. On the other hand, net present value simulation by applying a 5% discount rate was made in order to account for the possibility that farmers might earn income by saving their money in the Commercial Bank of Ethiopia at the contemporary saving rate (i.e., 5%).

Other factors held constant, increase in crop yield due to FYM and compost application potentially leads to low crop price and, consequently, to low farm income. Though the prices of most crops considered in this paper are less sensitive to supply changes, because the typical crops are staple food and storable (hence less sensitive to price changes especially in response to short-term yield variability), the 7.5 to 15% expected yield increase under the alternative management practices is assumed to be followed by a less proportionate (i.e., 5%) reduction in crop price.

3. Results and discussion

The average yields and values of selected indicators of crop production and use for the 18 sample farm households are presented in Table 3. Maize and teff are the two most important crops in terms of land allocation, followed by field peas and millet. At an average of 1,990 kg ha^{-1}, maize has the highest yield in the area. A significant proportion (i.e., 77%) of maize produced is used for household consumption while the rest is marketed. Similarly, the highest proportion of each of sorghum and millet is used for household consumption whilst crops such as field pea and pepper are produced mainly for income generation purposes. High unit prices observed for pepper, onion, and teff make it attractive for farmers to produce such crops mainly for markets. Such production, consumption, and market characteristics are expected to significantly influence farm household income and per capita nutrition.

Table 3. [HERE]

Yield levels observed for each crop under the baseline situation (Table 3) are assumed to increase by the respective rates specified in Table 2 under each management alternative. For example, maize yields under alternative management practice A2 are assumed to be 2,140 kg ha^{-1} during each planning year from 2014/15 to 2018/19 (as a result of 7.5% yield growth rate assumed to hold true under such a scenario). Similarly, maize yields for the 2014/15 production period under management practice A3, A4, and A5 is assumed to be 2,239 kg ha^{-1}, 2,189 kg ha^{-1}, and 2,289 kg ha^{-1} (as a result of the 12.5%, 10%, and 15% yield growth rate assumptions made to hold true under each scenario, respectively). The same assumption applies to yield dynamics for the rest of the crops considered in the analysis. Results of farm income and nutrition simulation under the alternative management practices are discussed below.

3.1 Simulated farm income

According to the simulated results, mean net present value obtainable during the five year planning period (2014/15 to 2018/19) both from the crop and livestock sub-sectors under the baseline situation (A1) is US$32,833 (Figure 3).[5] This amounts to US$6,566 per farm household

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[5] Mean simulated net present value is similar to the value observed at a 0.5 probability level in the cumulative distribution curve of the simulated 500 iterations. In Figure 3, the cumulative distribution curve under management

on an annual basis. Based on evidence from the baseline survey, each farm household has on average seven family members, making per capita net present value under the baseline situation about US$938. Mean simulated net present value increases to US$34,230 under the second management alternative (A2) in which farmers apply 5 t FYM ha^{-1} yr^{-1} during the entire planning period. Mean net present value reduces to US$34,172 under management alternative A3 in which farmers apply 10 t FYM ha^{-1} yr^{-1} during the first three years and 5 t FYM ha^{-1} yr^{-1} during the last two years of the planning period. Applying 5 t compost ha^{-1} yr^{-1} for the entire planning period (A4) decreases net present value to US$28,220. Mean farm income shows marginal improvement and increases to US$28,303 under management alternative A5 in which farmers apply 10 t compost ha^{-1} yr^{-1} during the first three years and 5 t compost ha^{-1} yr^{-1} during the last two years of the planning period. Though better crop yield is expected under soil amendment with compost than with FYM (Table 2), translating such high yield into farm income is likely undermined by high labor and material costs incurred in compost preparation and application. As a result, the highest increase in mean net present value (compared to that of the baseline situation - A1) is obtained under A2 (i.e., 4.3%), followed by A3 (4.1%) while it is negative under A4 (-14%) and A5 (-13.7%).

Figure 3. [HERE]

Figure 3 shows cumulative distribution function curves of respective net present values simulated through 500 iterations. The positive impact of management alternatives A2 and A3 on farm income is evident from the position of the respective distribution curves, which lie to the

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alternative A1 is at vertex with the 0.5 probability level (the vertical axis) when net present value (the horizontal axis) is at US$32,833.

right of the cumulative distribution function curve for the baseline situation (A1). At each probability level, farmers are likely to generate more income from adding 5 t ha^{-1} yr^{-1} and 10 t ha^{-1} yr^{-1} FYM (A2 and A3, respectively) compared to the baseline situation (A1, in which they apply only 50 kg DAP and 25 kg urea ha^{-1} yr^{-1}). However, despite the relatively high mean simulated net present value under A2, the cumulative distribution function curves for management alternatives A2 and A3 show significant overlap at most income levels, suggesting a lack of clear stochastic dominance of either of the two practices. On the other hand, the position of the cumulative distribution function curves for A4 and A5 suggest that farmers generate less income from combined compost and inorganic fertilizer application, (when compared to application of either only DAP and urea (A1) or DAP and urea combined with FYM (A2 and A3)).

The only difference to exist between alternative management practices (A2, A3, A4 and A5) with considerable impact on respective net farm income levels is crop yield. Though changes in yield might explain differences in attainable net farm income level under each management alternative, net farm income is influenced also by other variables (Eqn. 1). Moreover, difference in net farm income because of changes in yield can be obscured by the random nature of the stochastic simulation process used in the analysis, in which variables entering each simulation iteration are randomly drawn. Under such situations, it is possible that a negative impact of other variables, such as high production cost, undermines positive impact of high crop yield on net farm income.

The overall finding about the income impacts of alternative management practices is similar to that of Mekuria et al. (2013) which shows that plots amended with low-cost organic amendments make maize production an economically viable option. Similarly, Dawe et al. (2003) suggest the potential profitability of rice production systems in Asia under complementary applications of organic amendments and inorganic fertilizers. Huang et al. (2015) also show the positive yield impact of adaptive farm management practices implemented by farmers in China.

3.2 Simulated nutrition

As nutrition level is directly related to quantity and type of food consumed, organic amendment interventions that increase crop and livestock yield are highly likely to increase the nutrition level of farm households. This holds true to the extent that the proportion of crop and livestock products consumed by farm households under alternative management scenarios remains at or above that consumed under the baseline situation. As shown in Table 3, the proportion of crop consumed by farm households ranges from as high as 77% in the case of maize to only 6% in the case of pepper. It is assumed in this study that farm households maintain such proportions in consuming crops from harvests under each management alternative. This is on the ground that farm households are likely to remain subsistent with no major changes observed in their production and consumption behaviors through the planning period. Consequently, more crop yield as a result of each alternative management practice likely results in more nutrient gains. Potential nutrient gains from crop consumption under alternative management scenarios are quantified based on crop-specific quantity of each nutrient type (Table 4).

Table 4. [HERE]

According to the simulated results suggests daily kilocalories per adult equivalent (which is about 7,687 under the baseline situation - A1) increases to 8,358 under management alternative

A2 and to 8,309 under management alternative A3. It increases to 8,165 under management alternative A4 and to 8,705 under A5. Compared to the minimum daily kilocalorie requirement considered applicable for the area (1,750 per adult equivalent), all proposed organic soil amendment alternatives improve farm household nutrition (Figure 4). The highest daily kilocalorie per adult equivalent is secured from management alternative A5, likely due to the highest yield growth rate (15%) assumed to be achieved by farmers under such management alternative.

Figure 4. [HERE]

Alternative organic soil amendment practices positively affect protein, fat, calcium, and iron level that farm families can secure (Figure 5). Available protein, fat, calcium, and iron levels under each alternative practice increases when compared to respective levels obtainable under the business as usual situation. The only exception is Vitamin A in which alternative practice A2 and A4 fail to increase available levels above that of the baseline situation (A1) and none of the management alternatives fulfills the daily required minimum (0.06 grams). Perhaps this is because of the limited vitamin A content of the typical crop types considered in the study. Management alternative A5 secures the highest nutrient gain for both nutrient types, followed by management alternative A3, A2, and A4.

Figure 5. [HERE]

The highest nutrient gain as a result of alternative organic soil amendment interventions is found to be vitamin A under management alternative A5 and A3, followed by calcium under

A5, A3 and A2 (Figure 6). Each A5 and A3 practice increases Vitamin A levels by 100% and calcium by 80% and 67%, respectively. Provided crop proportion consumed by farm families remains similar to that of the baseline situation (or it is not substantially reduced, if any), yield increases as a result of organic soil amendment tends to increase nutrient levels secured by farm households.

Figure 6. [HERE]

3.3 Sensitivity to discount rate changes

Compared to the simulated income levels at 10% discount rate, those simulated at 15% discount rate reduce in the case of all management alternatives. However, the values remain positive, suggesting profitability of the practices under a higher discount rate. The relative importance of alternative practices in terms of contribution to net farm income remains identical to patterns observed under 10% discount rate (Figure 7 a and b). On average, mean simulated net present value reduces by 12% as a result of discount rate increase from 10 to 15% and increases by 16% as a result of discount rate reduction from 10 to 5%.

Figure 7. [HERE]

3.4 Sensitivity to producer price change

Contrary to expectations, the simulation results show improvement in mean farm income as a result of crop price reduction (Table 5). This might be due to consumer income effect of price reduction in which consumers' real income increases due to reductions in the prices of products they purchase (consumers buy same quantity of products with less expenditure). It is possible that farm households in the study area are net buyers of some of the particular food crops considered in the analysis. According to the evidence from survey results, farm households purchase maize, sorghum, onion, wheat and other crops. Hence, price reduction for these crops likely reduces net buyer farm households' expenditure and affects net farm income positively. The majority of evidence from sensitivity test results is therefore of robust net farm income from FYM soil amendment and economic betterment of farm households.

Table 5. [HERE]

4. Conclusions

Decisions on soil-based interventions to improve agricultural productivity can be informed using ex-ante simulated evidence on farm-level impacts. Simulated results in this study show positive yield, income, and nutrition impacts from organic soil amendments. The evidence is encouraging for policy makers to promote such practice adoption and scaling-out.

However, cash flow and income impacts of organic soil amendment practices can be sensitive to associated material and labor costs. From a farm income point of view, costs associated with compost preparation and application can make organic soil amendment less attractive to generally risk-averse farmers. It is therefore necessary to ensure that soil-based interventions and technologies for ecosystem restoration are affordable to farmers and also have significant yield impact to offset costs.

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Table 1. Selected socio-economic characteristics of the study area under the baseline situation (2014/15 production period)

Item	Indicator
Number of experimental farm households	18
Number of adult equivalent family members	122
Total cultivated land (ha)	49
Number of major crops cultivated	8
Number of cows (head)	39
Number of oxen (head)	37
Annual milk production (liter/head)	1,478
Average price of milk (US$/liter)	0.50

Source: Baseline survey on 18 farm households.

Table 2. Management alternatives for organic soil amendment in Halaba special *woreda*

Baseline situation	Alternative management practice	Change in yield (%)
A1 = Application of 50 kg DAP ha^{-1} + 25 kg UREA ha^{-1}	A2 = A1 + FYM (5 t ha^{-1} yr^{-1}) for the entire planning period	7.5
	A3 = A1 + FYM (10 t ha^{-1} yr^{-1}) for the first three years only and A1 + FYM (5 t ha^{-1}) for the last two years only)[a]	12.5
	A4 = A1 + Compost (5 t ha^{-1} yr^{-1}) for the entire planning period	10.0[b]
	A5 = A1 + Compost (10 t ha^{-1} yr^{-1}) for the first three years only and A1 + Compost (5 t ha^{-1} yr^{-1}) for the last two years only)[b]	15.0[b]

Note: [a] Continuous application of 10 t ha^{-1} yr^{-1} of either farm yard manure (FYM) or compost in the first three years (2014/15-2016/17) might lead to residual nitrogen availability and improvement in soil properties, making it reasonable to reduce application rate of such organic amendments by half (i.e., to 5 t ha^{-1} yr^{-1}) during the last two years (2017/18 - 2018/19) of the planning period.

[b] Experimental trials conducted on farm fields in the study area show better yield performance of fields treated with compost (compared to fields treated with same rate of FYM). Hence, annual crop yield growth rate on fields treated with compost is set at a higher level compared to that of fields treated under FYM.

Table 3. Average crop yield and values of selected production indicators

Crop	Area	Yield ($kg\ ha^{-1}$)					Proportion	Price	Production costs (US$/ha)		
	(ha)	A1[a]	A2[b]	A3[c]	A4[d]	A5[e]	consumed	(US$/kg)	Seed	Fertilizer	Others
Maize	19.0	1,991	2,140	2,239	2,189	2,289	0.8	0.3	29.7	83.8	99.8
Sorghum	2.5	1,300	1,397	1,462	1,430	1,495	0.6	0.3	7.1	16.8	65.6
Millet	3.1	1,233	1,325	1,387	1,356	1,418	0.6	0.4	8.8	39.1	74.0
Onions	0.1	750	806	843	825	862	0.6	0.7	84.7	0.0	19.7
Wheat	0.5	1,400	1,505	1,575	1,540	1,610	0.6	0.4	103.2	123.7	78.5
Teff	16.5	817	878	919	898	939	0.4	0.6	30.8	86.0	71.2
Peas	6.5	1,253	1,347	1,409	1,378	1,441	0.4	0.5	31.4	59.0	70.0
Pepper	0.8	453	487	510	498	521	0.1	1.5	6.8	234.6	279.6

Note: [a] Refers to observed crop yield during 2014/15 under the baseline situation and [b, c, d,] and [e] refer to estimated crop yield in 2014/15 under alternative management practice A2, A3, A4, and A5, respectively.

Table 4. Nutrient coefficients used in quantifying farm household nutrition benefits from each crop type under alternative management practices

	Maize	Haricot bean	Teff	Wheat	Sesame	Niger seed	Millet	Tomato
Energy (Kcal/kg)	3,610.00	970.00	1,010.00	3,640.00	1,640.00	4,000.00	1,190.00	180.00
Protein (g/kg)	69.30	20.20	38.70	103.30	88.60	230.00	35.10	8.80
Fat (g/kg)	38.60	1.90	6.50	9.80	25.90	1,000.00	10.00	2.00
Calcium (g/kg)	0.07	0.02	0.49	0.15	0.49	3.19	0.03	0.10
Iron (g/kg)	0.02	0.00	0.02	0.01	0.03	0.00	0.01	0.01
Vitamin A (g/kg)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

Table 5. Mean net present value of farm income under 5% reduction in crop price

	Management alternatives				
	A1*	A2	A3	A4	A5

Mean net present value (US$) at 0.1 discount rate and no reduction in crop price	32,833	34,230	37,172	28,220	28,303
Mean net present value (US$) at 0.1 discount rate and a 5% reduction in crop price	32,833	34,415	34,363	28,407	28,477

Note: * The assumption of 5% reduction in crop price does not apply to the baseline scenario (A1).

Figure 1. Study sites in Halaba special *woreda*

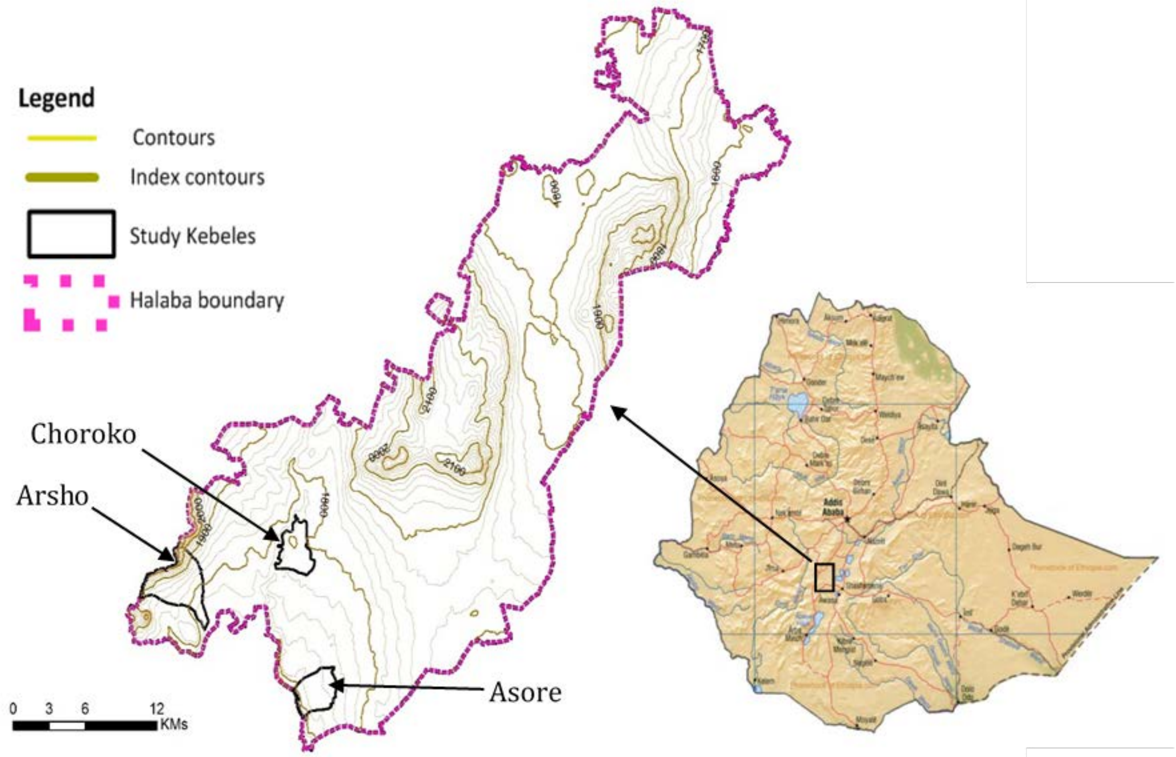


Figure 2. A simple schematic of FARMSIM model

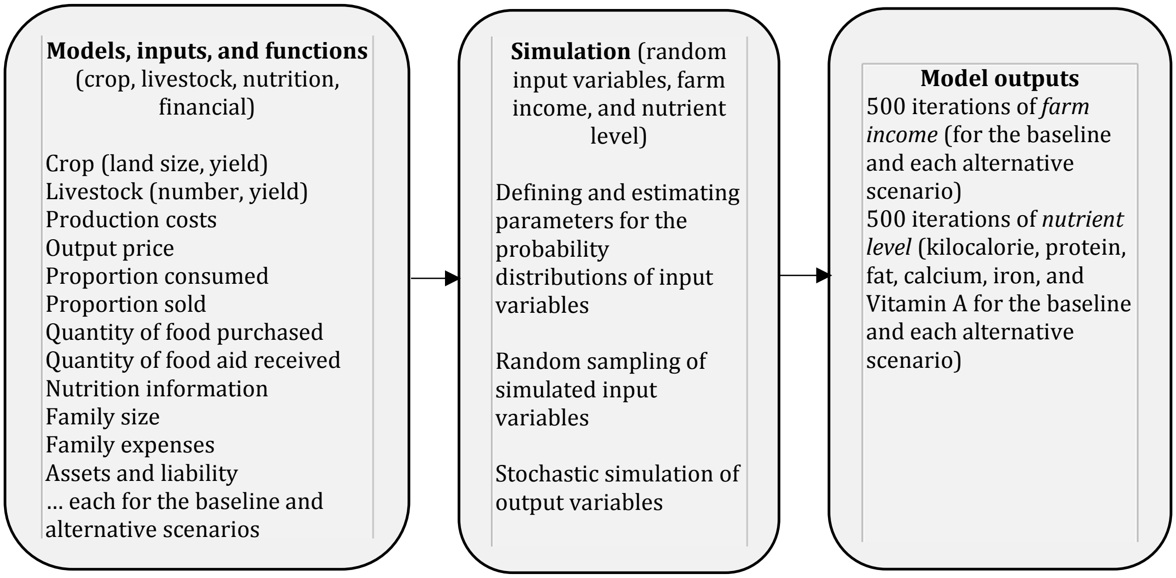
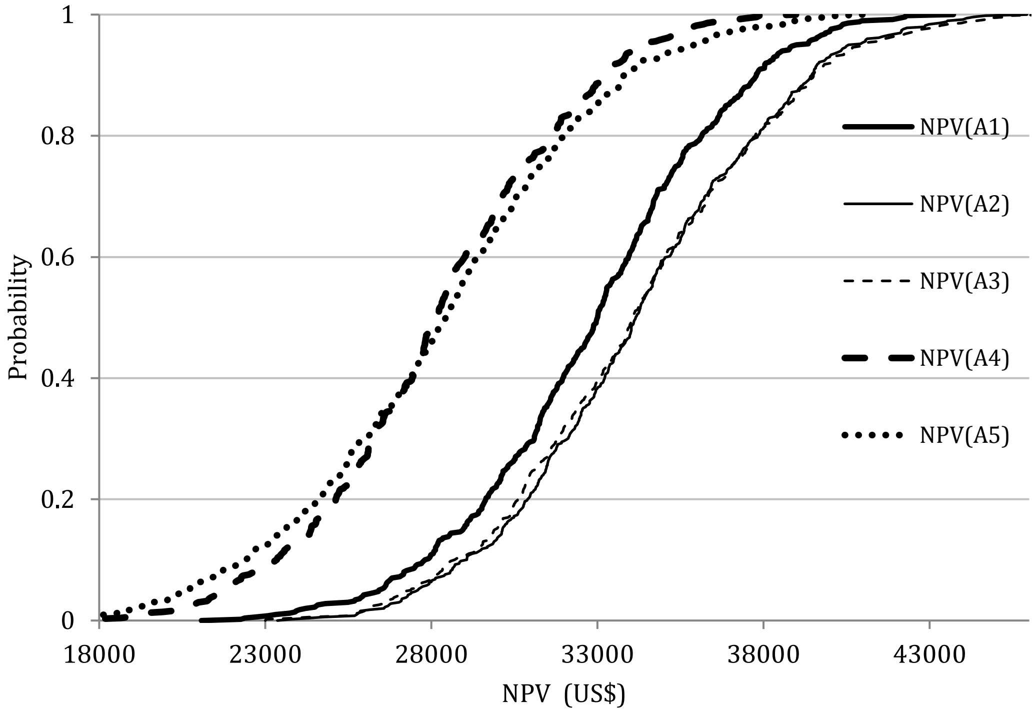
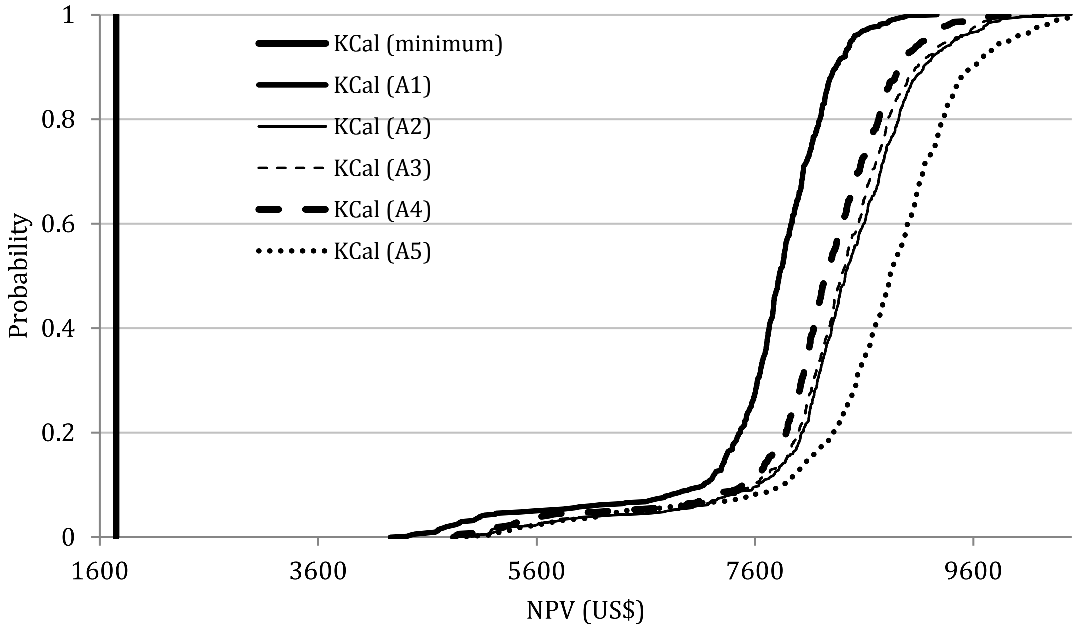


Figure 3. Cumulative distribution function of simulated net present value under alternative organic soil amendment practices (discount rate = 10%)



Note: NPV stands for net present value.

Figure 4. Cumulative distribution function of average daily kilocalories available under alternative organic soil amendment practices



Note: NPV stands for net present value and Kcal for kilocalories.

Figure 5. Nutrient level secured under alternative organic soil amendment practices

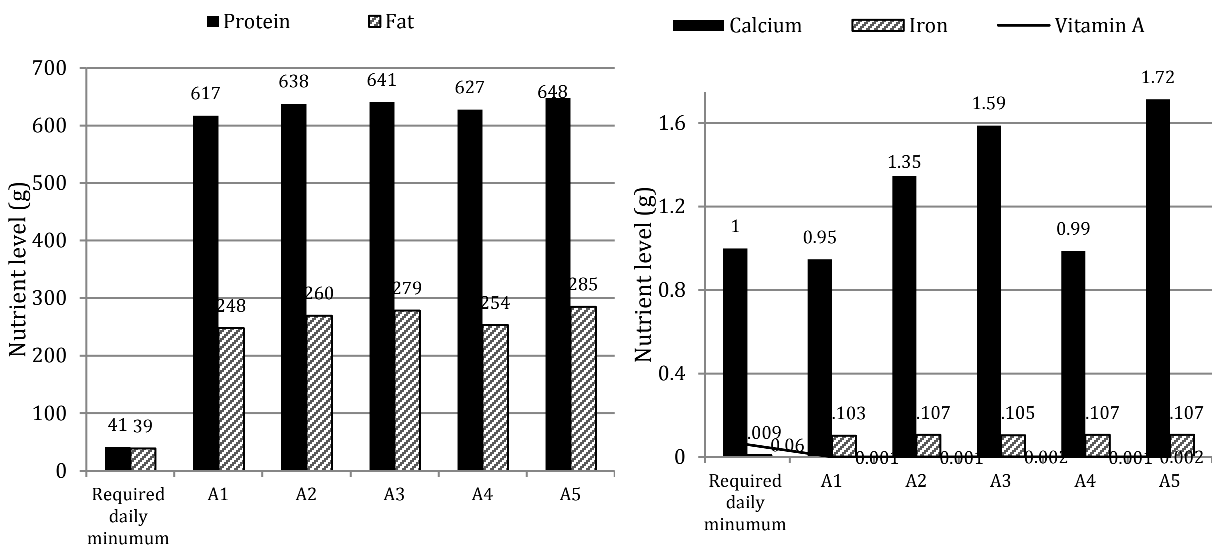


Figure 6. Additional nutrients secured under alternative organic soil amendment practices (%)

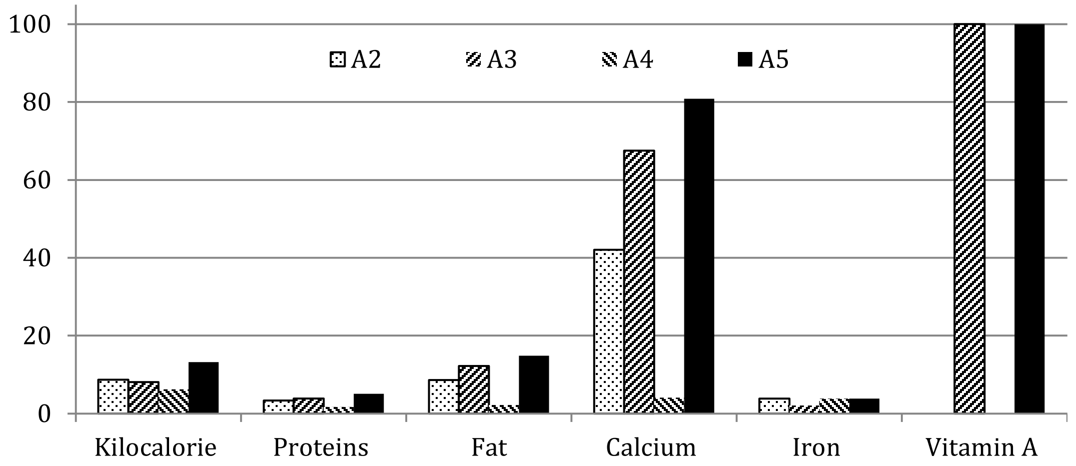
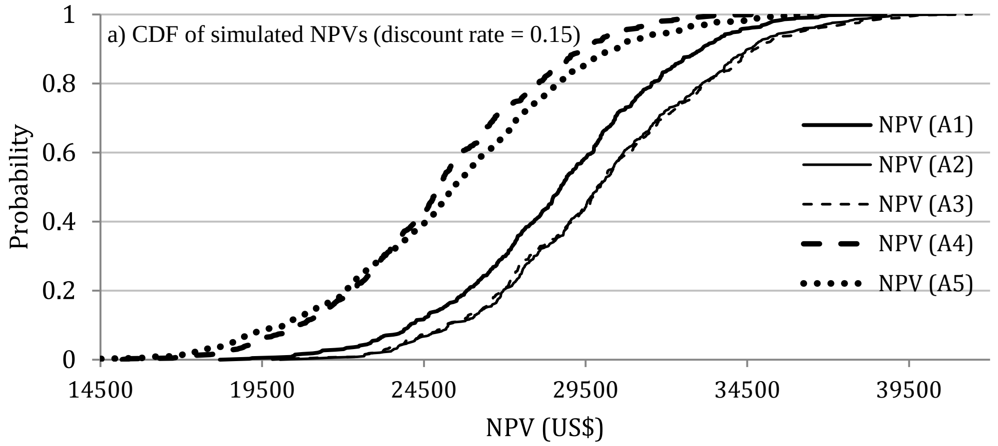
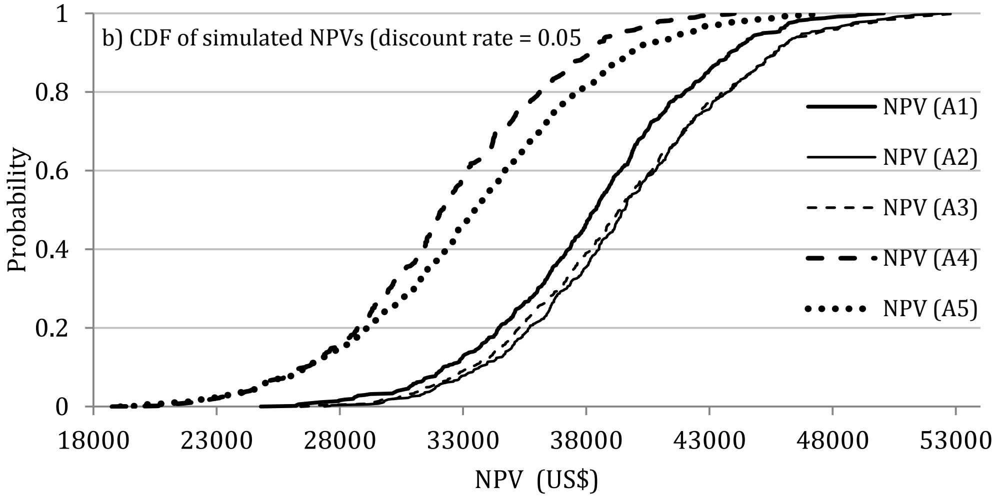


Figure 7. Cumulative distribution function of net present value under alternative organic soil amendment practices (discount rate = 15% and 5%)





Note: CDF stands for cumulative distribution function and NPV for net present value.