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Productivity, profitability and partial nutrient balance in maize-based conventional and organic farming systems in Kenya

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ABSTRACT

In 2007 two long-term trials were established in Kenya to contribute research-based evidence to the global debate on the productivity, economic viability and sustainability of different agricultural production systems. These trials compare conventional (Conv) and organic (Org) farming systems at high and low input levels at two locations, i.e. Chuka, with Humic Nitisols, high inherent soil fertility and rainfall, and Thika, with Rhodic Nitisols with low soil fertility and rainfall. The high input systems (High) represent commercial-scale, export-oriented production that uses the recommended amounts of fertilisers, pesticides and irrigation water to generate high yields, whilst the low input systems (Low) represent local smallholder practices, using relatively few fertilisers and pesticides and operating under rain-fed conditions. The conventional systems received synthetic fertilisers and organic manure, whilst the organic systems only received organic inputs. The trials so far have consisted of a 6-season, 3-year, crop rotation with maize (*Zea mays* L.) planted in the long rainy seasons (March-September), and vegetables in the short rainy seasons (October – February). Generally, there were no significant differences in the dry matter yields and nutrient uptake by maize, baby corn or beans between the conventional and organic systems at either site. Similar maize grain and baby corn yields were also obtained at Chuka. However, at Thika, maize grain yields in Org-High in 2007 (at conversion) were lower than the yields in Conv-High, but the yields became similar in 2010 (after conversion). At the same site the yields of maize grain under sole cropping in Org-Low were 3.2 times lower than the yields in Conv-Low in 2007 and 1.7 times lower in 2010. When intercropped with beans the yields of the two systems were similar. In the first two years profits from Conv-High were 0.5–1.8 times and 0.2–2.4 times higher than in Org-High when selling the produce at local (Chuka and Thika) and regional markets (Nairobi), but thereafter the profit from the two was similar, even when organic produce was sold at regular market prices. From the fifth year onwards Org-High attracted a price premium of 20 to 50% and this made it 1.3 to 4.1 times more profitable than Conv-High when selling on local and regional markets (in Chuka, Thika and Nairobi). Compared to Conv-High, partial N and K balances at the two sites were positive and higher in Org-High, except for N at Chuka. Our findings demonstrate that Org-High is productive, economically viable, resource-conserving and can contribute to sustainable agriculture production in Kenya depending on regional conditions and the crops cultivated.

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1. Introduction

About 80 percent of Africa's population depends on agriculture as their primary source of livelihood. It provides employment for about 60% of the economically active population, and for about 70 percent of the Africa's poorest people (ADB, 2010). Agriculture represents 30-40 percent of Africa's gross domestic product (GDP) and accounts for 60% of its exports (IFPRI, 2004). The main form of farming in sub-Saharan Africa (SSA), as in many other parts of the tropics, is simultaneous multispecies farming (i.e. the cultivation of a variety of crops on a single piece of land). This system is suited to small scale farmers seeking to cultivate for both subsistence and commercial purposes (Dixon et al., 2001; Vandermeer et al., 1998). Five major farming systems have been identified in SSA, that have different potentials for agriculture growth and poverty reduction. They are: maize-mixed farming; agro-pastoral; highland perennial; root and tuber crops and mixed cereal-root crops (Aurich et al., 2014; Dixon et al., 2001). Maize-based mixed farming systems cover 16% of the land area of SSA (Aurich et al., 2014). In East and Southern Africa, maize-based mixed farming is the most important food production system, mainly located in semi-humid to sub-humid agro ecological zones that extend across the plateau and highland areas at altitudes of 800 to 1500 m, stretching from Kenya and Tanzania through Zambia, Malawi, Zimbabwe on to South Africa, Swaziland and Lesotho (Dixon et al., 2001). It accounts for 246 million ha (10%) of the total land area in East and Southern Africa, 32 million ha (19%) of the cultivated area (of which just 0.4 million ha^{-1} is under irrigation) and involves about 60 million people (Dixon et al., 2001; Jaetzold et al., 2006).

The productivity (output per unit of land area) of maize-based mixed farming in East and Southern Africa is very low and is considered to be one reason for the persistence of rural poverty in the region (Akinnifesi et al., 2010; Jaetzold et al., 2006). The low crop productivity has been attributed to a number of factors that include low soil fertility and long-term soil degradation (e.g. acidification, compaction, loss of soil organic matter and nitrogen) (Amede, 2003; Henao and Baanante, 2006; Folberth et al., 2014) caused by deforestation, overgrazing, continuous and intensified cropping with inadequate replacement of soil nutrients (Henao and Baanante, 2006; Sileshi et al., 2010) and a low take up of sustainable resource management strategies (Omotayo and Chukwuka, 2009). There is a clear need to reverse the decline in soil fertility and the degradation of the natural resource base (land, water, forest, and biodiversity). This is a key to increasing and sustaining crop productivity which, in turn, will increase food security and reduce hunger and poverty. The most frequently recommended options to achieve this are to develop conventional agriculture, diversify production systems or intensify existing production patterns (Dixon et al., 2001; Folberth et al., 2014). However, in most countries in SSA the potential of conventional agriculture, based around monocultures, mechanisation and the use of synthetic inputs such as chemical fertilisers and pesticides (Beus and Dunlap, 1990) is limited by the high costs of doing so. There are other limiting factors too: the often highly variable soils, high P fixation capacity (Kwabiah et al., 2003; Nziguheba et al., 1998) and large within-farm soil fertility gradients (Vanlauwe et al., 2006). These features have led many to raise serious concerns about potential of conventional agriculture to improve productivity and provide sustainable yields in SSA (see Rigby and Càceres, 2001).

Organic agriculture is an approach that aims to close nutrient cycles and has the potential to improve the use efficiency of nitrogen and phosphorus (Badgley et al., 2007). Organic agriculture combines a number of practices including the application of organic fertilisers, intercropping with nitrogen-fixing trees or legumes or with other crops that produce synergies, extended crop rotations with greater phenological diversity of crops, biological pest control, the use of locally adapted seeds/breeds, and the re-integration of animals on farms. It also precludes the use of synthetic inputs such as pesticides, herbicides, hormones and the preventive use of antibiotics (all defined by organic standards). However, there are questions about whether organic agriculture can achieve production and productivity levels that are comparable to conventional agriculture. Factors that limit the productivity of organic agriculture can include shortages of, and poor quality, organic materials and the slow nutrient release of organic inputs which can be insufficient to meet crop nutrient demands at periods of peak demand (Murwira et al., 2002; Omotayo and Chukwuka, 2009). From a short term perspective, organic agriculture is generally seen as unable to support and sustain the high levels of productivity needed to meet local and global food demand (Kirchmann et al., 2008; Seufert et al., 2012). But from a longer term perspective it is believed to hold more prospect of being sustainable and stable (Reganold and Wachter, 2016).

Long-term farming systems experiments (LTEs) are an important way of evaluating the potentials and limitations of different farming systems against sustainability criteria (productivity, economic viability and resource-conservation). There is a long tradition of undertaking farming systems comparisons in temperate climates (Mäder et al., 2002; Pimentel, 2005). These trials are often run over long periods in order to capture the impacts on soil productivity. Yields in temperate regions have been found to be 20 to 25% lower in organic systems than in conventional ones (Seufert et al., 2012), although nutrient and energy efficiency, soil fertility and biodiversity were found to be enhanced in organic systems (Bengtsson et al., 2005; Mäder et al., 2002; Pimentel, 2005). There is very little long-term data on the performance of organic and conventional systems in the tropics and subtropics (Bationo et al., 2012; Seufert et al., 2012). Moreover, in Africa such trials have often been faced with the challenges of inconsistency in data collection and management or funding constraints, which make it difficult to evaluate their performance (Bationo et al., 2012). In addition the studies that have been undertaken did not compare the performance of small holder and commercial-scale farms under multispecies farming, or under different geographical and weather conditions, features which are all typical of African farming systems.

In view of this knowledge gap, the Research Institute of Organic Agriculture (FiBL), in collaboration with its research partners has established a network of long-term farming systems comparison trials in the tropics with field sites in Kenya, India and Bolivia (Forster et al., 2013). These field trials aim at comparing the agronomic, economic and ecological performance of conventional and organic farming systems under different ecological zones, soil types, and management practices. The hypotheses of this study are that: (a) organic farming systems will match the productivity and profitability of conventional farming systems under intensive cropping over the medium to long term (6-20 years or more); (b) under continuous cultivation, conventional and organic farming systems have different effects on nutrient exports and partial nutrient balance. The specific objectives were: (i) to assess and compare the productivity (measure of output produced per unit of land area) of organic and conventional farming under high input and low input systems in two different sites in Kenya, (ii) to determine the profitability (the measure of revenue less production costs) of organic and conventional farming in high and low input systems, and (iii) to evaluate the effect of conventional and organic farming systems on nutrient exports and partial nutrient balance.

2. Materials and methods

2.1. The Long-Term Systems Comparison Trials in Chuka and Thika

2.1.1. Site description

The Long Term Systems Comparison Trial sites at Chuka and Thika are situated in the sub-humid zones of the Central Highlands of Kenya. The trials were established in 2007 and are expected to run for 20 years. Both areas are characterised by a bimodal rainfall pattern (long rainy seasons from March to June and short ones from October to December). Chuka is situated in the UM 2 agroecological zone, also called the Main Coffee Zone and is located at 1,458 m above mean sea level in Tharaka Nithi County (37° 38.792' N & 0° 20.864' S), about 150 km away from Nairobi. The mean annual temperature at Chuka ranges from 19.2–20.6 °C and mean annual rainfall is 1373 mm. The trial site is located at Kiereni Primary School. Thika is situated in the UM 3 agroecological zone of the upper midlands, also called the sunflower-maize zone and the site is situated in the premises of the Kenyan Agricultural and Livestock Research Organisation, (KALRO) in Murang'a County. Thika is about 20 km away from Nairobi (37° 04.747' N and 1° 0.231' S) and lies at 1,500 m above mean sea level with an annual mean temperature ranging between 19.5 and 20.7 °C and mean annual rainfall is 840 mm. The soils at Chuka are Humic Nitisols while those at Thika are Rhodic Nitisols (Table 1) based on the FAO world reference base for soil resources (IUSS Working Group WRB, 2006; Wagate et al., 2010a,b).

2.1.2. Experimental design and management

Prior to setting up the trials, soil homogeneity tests of the sites were done in 2006 with maize grown as the sole crop without any inputs. Data about the maize yield and biomass, pH and total soil organic carbon were collected from 5 × 5 m plots which were used as a guide to block the trial sites at each location. Based on the data obtained from the homogeneity test, the experimental plots, each measuring 8 × 8 m, were then set up (with an inner net plot size of 6 × 6 m for data collection). Each treatment was applied in a Randomised Complete Block Design (RCBD) which was replicated four times in Chuka and five times in Thika. At each site conventional farming (Conv) and organic farming (Org) were compared at two levels of inputs: high inputs (High) representing export oriented, large scale production and low inputs (Low) representing small holder production largely for domestic use. The type of inputs and the amount of nutrients applied per crop in each cropping season (Table 2) in the conventional high input system (Conv-High) and the organic high input system (Org-High) were based on the recommendations of the Kenyan Ministry of Agriculture and the Japanese International Co-operation Agency's local and export vegetable growing manual (MOA/JICA, 2000). The ones in the conventional low input system (Conv-Low) and the organic low input system (Org-Low) were based on a survey done within a 20 km radius of the two experimental sites that assessed the practices of 35 households in Tharaka Nithi County (Chuka Area) and 25 in Murang'a County (Thika Area) (Musyoka, 2007; Székely, 2005; see supplementary sheet Annex 1).

Table 1
The initial soil characteristics (as means and standard errors) of the field replicates of the long-term systems comparison trial sites at Chuka and Thika, in the Central Highlands of Kenya.

		Chuka		Thika	
		0–20 cm	20–40 cm	0–20 cm	20–40 cm
Sand	[g kg^{-1}]	94 ± 8	80 ± 3	54 ± 7	62 ± 7
Silt	[g kg^{-1}]	166 ± 7	153 ± 5	141 ± 11	102 ± 8
Clay	[g kg^{-1}]	740 ± 9	767 ± 5	805 ± 14	836 ± 13
pH-H_2O		5.8 ± 0	6.1 ± 0	5.4 ± 0	5.7 ± 0.3
EC	[μS cm^{-1}]	138.7 ± 3.3	159 ± 6.2	119.8 ± 7.2	128.5 ± 14.6
CEC	[Cmolc kg^{-1}]	17.5 ± 0.5	14.8 ± 0.4	11 ± 0.3	10.1 ± 0.4
C_{org}**	[g kg^{-1}]	23.2 ± 0.8	21.1 ± 0.4	22.6 ± 0.2	18.3 ± 0.4
N_{tot}	[g kg^{-1}]	2.08 ± 0.03	1.78 ± 0.09	1.6 ± 0.04	1.48 ± 0.06
S	[mg kg^{-1}]	18.3 ± 0.1	12.4 ± 0.9	39 ± 2.3	26.6 ± 3
P	[mg kg^{-1}]	28.9 ± 1.9	12.1 ± 0.8	12.2 ± 0.6	2 ± 0.1
K	[Cmolc kg^{-1}]	1.25 ± 0.03	0.98 ± 0.03	1.28 ± 0.03	1.05 ± 0.17
Ca	[Cmolc kg^{-1}]	8.75 ± 0.29	8.6 ± 0.3	3.53 ± 0.19	3.8 ± 0.97
Mg	[Cmolc kg^{-1}]	2.28 ± 0.05	2.1 ± 0.04	1.9 ± 0.11	1.73 ± 0.31
Na	[Cmolc kg^{-1}]	0.2 ± 0	0.1 ± 0	0.15 ± 0.03	0.1 ± 0
Al	[Cmolc kg^{-1}]	0.01 ± 0	0.05 ± 0.03	0.1 ± 0	0.28 ± 0.02

2.1.3. Cropping systems

The crops and the cropping pattern of the trials in Chuka and Thika are shown in Table 2. The selection of crops for the high input systems (Conv-High and Org-High) and low input systems (Conv-Low and Org-Low) were based on reports by Székely (2005), Musyoka (2007) and MOA/JICA (2000). The crop rotations were based on farmers' practices in the area and the principle of crop rotation recommended by the Kenyan Institute of Organic Farming (KIOF) (Székely, 2005). In Conv-High and Org-High, maize (*Zea mays* L.), a staple food crop in the area was planted every year in the long rains season. In Conv-High it was planted as a sole crop. In Org-High it was planted as a relay-inter crop with *Mucuna pruriens.* One maize (Zea mays, var. H 513) and Baby corn (Zea mays var. Pana 14) seed was each planted per hole at an inter- and intra-row spacing of 75 cm × 30 cm in the high input systems whilst two maize seeds were planted per hole at an inter- and intra-row spacing of 75 cm × 60 cm in the low input-systems. The low input systems was intercropped with beans (Phaseolus vulgaris L, var. GLP 92) planted at an inter- and intra-row spacing of 75 cm × 30 cm (2 seeds per hole). Mucuna pruriens was planted four weeks after the maize emerged, as a relay crop at an inter- and intra-row spacing of 75 cm × 80 cm at two seeds per hole. When maize (*Zea mays* L.) is used as a vegetable it is known as 'baby corn' and consists of unfertilised young ears harvested 2 or 3 days after silk emergence (1–2 cm long). It is typically eaten whole, cob included. This is in contrast to mature corn, the cob of which is too tough for human consumption. In this paper each 6-season (3 year) rotation in all the systems is referred to as a cycle. Since the fields had been cropped for several years before the establishment of the trials, the 1st cycle also coincided with the period of conversion to organic management (according to IFOAM standards) in Org-High and Org-Low.

2.1.4. Management practices in the different farming systems

In Conv-High, farm yard manure (FYM) and Di-ammonium phosphate (DAP) were applied at planting at the rates shown in Table 2. Calcium ammonium nitrate (CAN) were applied when the maize was at the 8 leaf and tasseling stages. In Org-High compost (made from maize stover and farmyard manure (FYM), *Tithonia diversifoliar* (Tithonia), ash and rock phosphate were applied at planting. Tithonia was applied in a form of a mulch to supply a starter N two weeks after the maize emerged. At 6 leaves and tasselling stages Tithonia was again applied in a form of plant tea to supply N as a top dressing. At each time of Tithonia tea application, 12.5 kg of fresh and tender leaves of Tithonia was used per plot (size 8 × 8 m). The tender leaves of Tithonia was chopped into small pieces and soaked in plastic drums of water at a ratio of 1:5 (leaf to water). The open top of the drums containing the mixture were covered to avoid ammonia volatilisation and kept under shade. The mixtures were stirred once after every 3 days to allow for mineralisation until 10 to 14 days when the water had turned dark brownish green, an indication that most of the nutrients had dissolved into the water. The plant tea was sieved and the trash removed. The generated liquid was then diluted with water at the

Table 2
Recommended application rates of inputs and the cropping pattern in the 6 season-3-year crop rotation of the long term system comparison trial in Chuka and Thika, Kenya.

Farming system	Year in the cycle	Season	Crop	Description of inputs applied to maize and beans	Total N applied (kg ha^{-1})	Total P applied (kg ha^{-1})
Conv-High	2007/10	LS	Maize	7.5 t ha^{-1} FYM, 200 kg ha^{-1} DAP, 100 kg ha^{-1} CAN[a]	96	54
		SS	Cabbage	10 t ha^{-1} FYM, 200 kg ha^{-1} TSP, 300 kg ha^{-1} CAN	145	64
	2008/11	LS	Baby corn	11.3 t ha^{-1} FYM, 200 kg ha $^{-1}$ DAP, 100 kg ha^{-1} CAN[a]	113	60
		SS	French beans	7.5 t ha^{-1} FYM, 200 kg ha^{-1} DAP, 100 kg ha^{-1} CAN[a]	113	60
	2009/12	LS	Baby corn	11.3 t ha^{-1} FYM, 200 kg ha $^{-1}$ DAP, 100 kg ha^{-1} CAN[a]	113	60
		SS	Irish Potatoes	7.5 t ha^{-1} FYM, 300 kg ha^{-1} TSP, 200 kg ha^{-1} CAN[a]	103	83
Org-High	2007/10	LS	Maize/Mucuna[b]	7.5 t ha^{-1} FYM-compost, 364 kg ha^{-1} RP, 5.4 t ha^{-1} *Tithonia* mulch & 3.9 t ha^{-1} *Tithonia* fresh leaves used as tea	96	54
		SS	Cabbage	15 t ha^{-1} FYM-compost, 400 kg ha^{-1} RP, 6 t ha^{-1} *Tithonia* mulch & 6 t ha^{-1} *Tithonia* fresh leaves used as tea	145	64
	2008/11	LS	Baby corn/ Mucuna[b]	11.3 t ha^{-1} FYM-compost, 364 kg ha^{-1} RP, 5.4 t ha^{-1} *Tithonia* mulch & 3.9 t ha^{-1} *Tithonia* fresh leaves used as tea	113	60
		SS	French beans	11.3 t ha^{-1} FYM-compost, 364 kg ha^{-1} RP, 5.4 t ha^{-1} *Tithonia* mulch & 3.9 t ha^{-1} *Tithonia* fresh leaves used as tea	113	60
	2009/12	LS	Baby corn/ Mucuna[b]	11.3 t ha^{-1} FYM-compost, 364 kg ha^{-1} RP, 5.4 t ha^{-1} *Tithonia* mulch & 3.9 t ha^{-1} *Tithonia* fresh leaves used as tea	113	60
		SS	Irish Potatoes	11.3 t ha^{-1} FYM-compost, 581 kg ha^{-1} RP, 8.2 t ha^{-1} *Tithonia* mulch	103	83
Conv-Low	2007/10	LS	Maize[b]	5 t ha^{-1} of fresh FYM, 50 kg ha^{-1} DAP	31	18
		SS	Kales/Swiss chard	1 t ha^{-1} of fresh FYM, 50 kg ha^{-1} TSP, 60 kg CAN	20	13
	2008/11	LS	Maize[b]	5 t ha^{-1} of fresh FYM, 50 kg ha^{-1} DAP	31	18
		SS	Grain legumes	No fertilizer application	NA	NA
	2009/12	LS	Maize/beans[b]	5 tha^{-1} of fresh FYM, 50 kg ha^{-1} DAP	31	18
		SS	Irish potato Potatoes	2 t ha^{-1} of fresh FYM, 100 kg ha^{-1} DAP,	27	25
Org-Low	2007/10	LS	Maize[b]	5 t ha^{-1} FYM-based compost, 100 kg ha^{-1} RP, 1.36 kg ha^{-1} *Tithonia* mulch	31	18
		SS	Kales/Swiss chard	1 t ha^{-1} of fresh FYM-compost, 1.2 Tithonian mulch, 90 kg ha^{-1}, 1.2 t ha-1 Tithonia fresh leaves used as tea	20	13
	2008/11	LS	Maize/beans[b]	5 t ha^{-1} FYM-based compost, 100 kg ha^{-1} RP, 1.36 kg ha^{-1} *Tithonia* mulch	31	18
		SS	Grain legumes	No input application	NA	NA
	2009/12	LS	Maize/beans[b]	5 t ha^{-1} FYM-based compost, 100 kg ha^{-1} RP, 1.36 kg ha^{-1} *Tithonia* mulch	31	18
		SS	Potatoes	2 t ha^{-1} FYM-based compost, 200 kg ha^{-1} RP, 2.72 kg ha^{-1} *Tithonia* mulch	27	25

[1]Conv-High, conventional high input system; [2]Org-High, Organic high input system; [3]Conv-Low, conventional low input system; [4]Org-Low, organic low input system. Assumptions: FYM/compost (DW): 1.12% total N and 0.3% P (Lekasi et al., 2003); DM of FYM is assumed to be 40%; Tithonia diversifolia (DW): 3.3% N; 0.31% P; 3.1% K (Nziguheba et al., 1998); DM of Tithonia = 20%; Phosphate rock from West Africa (Finck): 11 –13% P.

[a] CAN = calcium ammonium nitrate, CAN was applied as top-dressing in all the crops: In two splits for high input only for specific crops in low input.

[b] Compost preparation starts with the indicated amount of Fresh farmyard manure (FYM) and was applied at planting. DAP = Di-ammonium phosphate; TSP = triple superphosphate; RP = rock phosphate; LS, long rain season; SS, short rain seasons. Tithonian mulch was applied after crop germination as starter N. Organic high input system also received maize stover.

ratio of 1:2 (leaf tea to water) to reduce the tea concentration. The plant tea was then applied equally to all the plants in the plot. The trash that was removed was also distributed in between the planting rows in the plot. In addition, crop residues from previous crops were retained within the system. In Conv-Low FYM and DAP were applied at planting. In Org-Low decomposed FYM and rock phosphate were applied at the time of planting. In the two study areas Tithonia grows in the wild and is also grown as a hedge plant by the majority of farmers (Annex 1, supplementary sheet). Also, about 77% of the farmers had at least one cow that generates on the average 6 tonnes (fresh weight) of manure per year. The presence and availability of Tithonia and manure help to address the often common challenge that a lack, or limited availability, of organic inputs is a barrier to the widespread adoption of organic agriculture by small holder farmers. The plant health measures that were taken are shown in Table 3. Pests (stem borer and termites) were managed based on bi-weekly scouting reports and a spraying calendar in Conv-High and Org-High. In Conv-Low and Org-Low pests and diseases were randomly managed. In all the systems hand hoeing was done at every planting in each season up to a depth of 20 cm followed by two weeding with a matchet (as is generally practiced in Kenya, except in very large scale commercial production of wheat, floriculture and pineapples). The amount and frequency of irrigation water, type of pesticides and their rate of application are indicated in Table 3.

2.1.5. Field Data Collection

Agronomic data were collected using the entire plants from a net plot of 6 × 6 m. The dry weight of the maize and beans was determined at a moisture content of 13%. Baby corn (fresh green young cobs) data was collected at 3–4 day intervals at the beginning of harvest and at 6–8 day intervals at the later stages of harvest. Baby corn was sorted into marketable and unmarketable yields (based on specifications provided by export companies) and the marketable yields were used to calculate the yields per hectare. All the data on yields and gross margins presented in the paper are least square means values. Economic data (i.e. labour, input and transport costs and market prices) at Chuka, Thika and Nairobi were collected for each season in all the systems.

2.1.6. Weather data

The daily precipitation data used in this paper were obtained from weather stations that were installed at the two experimental sites at the start of the project. To highlight the rainfall distribution over time, cumulative precipitation throughout the season was calculated and presented graphically. The effect of the amount and

Table 3
The amount and frequency of irrigation water and type and rate of pesticides applied in the long term system comparison trial in Chuka and Thika, Kenya.

Farming Systems	Year	Crop	Amount of irrigation water applied per season ($m^3 ha^{-1}$)		Frequency of irrigation		Pest & disease management
			Chuka	Thika	Chuka	Thika	Type of chemicals† and pest control for termites and stem borer
Conv-High[a]	2007/2010	Maize	* (445.50)	* (**)	* (8)	* (**)	Bulldock (Beta-cyfluthrin) [Bulldock + Dragnet (Permethrin)]
	2008/2011	Baby corn	* (167.06)	* (1698.47)	* (3)	* (18)	Bulldock (Beta-cyfluthrin) [Bulldock + Fungi icipe isolate 30‡)]
	2009/2012	Baby corn	668.25 (365.31)	4009.50 (692.50)	12 (4)	31 (11)	Bulldock + Wood Ash [Bulldock + Confidor (Iimidacloprid)]
Org-High[b]	2007/2010	Maize	* (445.50)	* (**)	* (8)	* (**)	Neem (*Azadirachta indica*) oil extract [Delfin (*Bacillus thuringiensis*) + Fungi isolate 30]
	2008/2011	Baby corn	* (167.06)	* (1698.47)	* (3)	* (18)	Thuricide (*Bacillus thuringiensis* v. Kurstaki) [Delfin (*Bacillus thuringiensis*) + Fungi isolate 30]
	2009/2012	Baby corn	668.25 (365.31)	4009.50 (692.50)	12 (4)	31 (11)	Aschook (*A. indica*) + Dipel [Delfin (*Bacillus thuringiensis*) + Fungi isolate 30]
Conv-Low[c]	2007/2010	Maize	NA	NA	NA	NA	Wood ash + soil [Wood ash + Dragnet]
	2008/2011	Maize/beans	NA	NA	NA	NA	Wood ash + soil [Wood ash + Plant extract$^{\beta}$]
	2009/2012	Maize/beans	NA	NA	NA	NA	Wood ash + soil [Wood ash + Confidor]
Org-Low[d]	2007/2010	Maize	NA	NA	NA	NA	Wood ash + Soil
	2008/2011	Maize/beans	NA	NA	NA	NA	Wood ash + Soil [Wood ash + Plant extract]
	2009/2012	Maize/beans	NA	NA	NA	NA	Wood ash + Soil [Wood ash + Plant extract]

*There was no irrigation in 2007 and 2008 first season because irrigation facility was not installed. The crop was grown under rain-fed condition; **No irrigation because there was adequate rainfall amount and distribution in 2010 at Thika; Values in brackets are for 2010, 2011 and 2012; pesticides applied in 2010, 2011 and 2012 are shown in squared brackets; $^{\beta}$Plant extracts are concoction supplied by icipe. NA, not applicable because the crop was grown only under rain- fed condition. ‡ *Metarhizium anisopliae*; †Rate of chemical for pest control; Achook 2 L h^{1}, Buldock 7 kg ha^{1}, Fungi icipe isolate 30 313 kg ha^{1}, Confidor 1.9 L ha^{1}, Neem oil extract 3.3 L ha^{1}, Thuricide 0.5 kg ha^{1}, Dipel 0.5 kg ha^{1}, Delfin 0.3 kg ha^{1}, Wood ash 75 kg ha^{1}, Dragnet 1.6 L ha^{1} and Plant extract 1171 L ha^{1}.

[a] Conv-High, conventional high input system.
[b] Org-High, Organic high input system.
[c] Conv-Low, conventional low input system.
[d] Org-Low, organic low input system.

distribution of rainfall on yields was assessed through computing the occurrence of dry spells that exceeded 5, 10, 15 or 20 consecutive days, using a rainfall threshold value of 1 mm. The selection of the rainfall threshold value was based on the argument of Ngetich et al. (2014): that when there is less than 1 mm of rainfall the water remains on the surface of the soil or on the plant cover and readily returns to the atmosphere through evapotranspiration.

2.2. Soil, manure, compost and plant tissue analysis

Soil pH was analysed using a 1:2.5 soil to water ratio (w/w) as described by Okalebo et al. (2002). Soil particle size was determined by the hydrometer method (Bouyoucos, 1962). Potassium (K), calcium (Ca), magnesium (Mg), sulphur (S) were analysed after extraction using 20 mL of Mehlich 3 solution as described by Mehlich (1984). Total N was determined by the Kjeldahl method as described by Gupta (1999) and P by the Olsen method according to Okalebo et al. (2002). Exchangeable aluminium (Al) was analysed with a spectrophotometer (model Shimadzu 1240) at a wave length of 567 nm after extraction using potassium chloride (Kennedy and Powell, 1986). Organic carbon was assessed by the wet oxidation method (Robinson, 1994). Compost and manure samples were air-dried under shade to a constant weight and ground ($<$0.25 mm, 60 μm mesh). Afterwards, 0.3 g of the air dried samples were analysed for N, P and K, as described by Okalebo et al. (2002). To evaluate N, P, and K uptake and dry matter accumulation, two plants were selected at random from outside the net plot area of 6 × 6 m at harvest and the above ground plant biomass samples were oven-dried at 60 °C to a constant weight to determine the dry matter yield (DMY). Dried plant samples were ground into a fine powder in a mill and sieved ($<$0.25 mm, 60500 μm mesh). Afterwards, 0.3 g of each of the ground samples was analysed for N using the Kjeldahl method (Okalebo et al., 2002). For P and K, 0.5 g of each ground samples was destroyed through volatilisation or oxidation by dry combustion in a Muffle furnace at a temperature of 500 °C for 6 hours, and the soluble mineral constituents, which form the main part of the residual ash, were dissolved in dilute acid (Hydrochloric acid, HCl). Any silica present was dehydrated and therefore made insoluble. The sample solution (or filtrate) was run on a spectrophotometer and flame photometer to determine P and K (Okalebo et al., 2002).

2.3. The productivity and economic evaluation of farming systems

Productivity was measured as the output (economic marketable yield) per plot and is given on a per hectare basis. In Kenya low input farmers mainly sell their produce on the local market or at the farm gate, whilst the high input farmers mainly sell to regional or export markets. Local information sources indicated that some low input farmers, especially those close to the regional markets, also sell their produce on these markets. This led us to analyse and compare the profitability of the farming systems under both local and regional market conditions. The prices were standardised by ensuring that average wholesale prices were used for all products across the different markets considered. This was to take care of any fluctuation in inputs in each year as well as to eliminate variations that might occur as a result of retailers' interventions. Market prices were collected from RATIN (http:/www.ratin.net) for conventional produce on regional markets (Table 4), premium market prices for organic produce were collected from five organic shops for the regional market and from farmers and farmers' groups at Thika and Chuka for the local market (Table 4). Gross revenue was calculated by multiplying the economic marketable yields by the prevailing selling prices at the local markets (Thika and Chuka) and the regional market (Nairobi) (Table 4).

Profitability is a relative term derived from profit, where profit is total farm profits (gross revenue) minus total production costs (Lipsey, 1975).Total production costs can be classified into fixed costs and variable costs. There were no fixed costs except land which was common to all systems. Land was assumed to be owned by the farmer and not rented; the only costs calculated were the variable costs which were considered to make up the total production cost. In this case, the gross margin becomes the same as profit. Variable costs consisted of inputs, labour, any irrigation facility and transport costs associated with the production, harvesting and marketing stages. These inputs included seeds, synthetic fertilisers, rock phosphate, farmyard manure, compost, pesticides and water. Labour costs consisted of all field labour (for preparing the land, compost and manure, weeding, the application of fertilisers, watering and maintaining the irrigation facility, harvesting, sorting and shelling the maize), the time spent sourcing inputs and marketing. The labour was valued based on field labour time and the wage rate of hired farm labourers at Chuka and Thika. No market price was available for Tithonia mulch, tea or *Mucuna* mulch. Their valuations were based on the time taken to prepare them calculated at the prevailing wage rate for hired farm labourers at Chuka and Thika (as prescribed by the Kenya Government).

A straight-line depreciation method was used to calculate depreciation expenses by spreading the cost of the irrigation facility (tank, pipes, driplines and connectors) over its depreciation period with equal periodic charges. The suppliers of the irrigation facility guaranteed the tanks, pipes, and connectors for a period of ten years. We took this figure as the expected lifespan of the irrigation facility and applied it to the depreciation calculation (personal consultation with Irrigation Department of Kenyan Agriculture and Livestock Research Organisation, KALRO). Depreciation was calculated using the following equation:

Yearly depreciation value for each irrigation facility = [(Cost value-salvage value)/Depreciation period].

Transport costs include the cost of sending produce to the markets and the cost of purchasing inputs and irrigation materials for the high input systems. The prices of inputs were determined for every season from local retail shops at Chuka, Thika and Nairobi. The profitability of the two organic systems was calculated with and without the premium. With the premium, the certification cost was also factored into the total production costs. The costs of certification and inspection for organic production were based on prevailing national rates in Kenya. These consisted of a registration fee = 5000 Ksh (ca. 58.14$), an inspection fee = 7500 Ksh (ca. 87.21$) per day, report writing = 5000Ksh, (ca. 58.14$), and issuing a certificate = 5000 Ksh (ca. 58.14$) (personal contact with NESVAX control, Nairobi, Kenya). A benefit-cost ratio which shows the relationship between costs and benefits was also used to compare the performance of the farming systems. In our case the benefit cost ratio was calculated as the gross margin divided by the total variable production cost. The profitability of both organic and conventional systems was estimated for the direct effect of the fertilisers on the yields of maize, baby corn and beans. The residual fertiliser effect was not taken into consideration.

2.4. Nutrient input, output, export and partial nutrient balance

The N, P and K contents of all soil inputs applied in each of the systems (Table 2) were calculated to determine the specific nutrient inputs. Similarly, the nutrient contents of all the outputs (the above ground biomass for maize, baby corn and beans, grain yield for maize and beans, maize cobs and husks) were calculated. Nutrient fluxes between nutrient pools within the system (e.g. litter fall) and other input pathways such as mineral weathering, deep soil exploitation, biological N fixation; and outputs such as volatilisation and leaching were not considered in this calculation. Outputs by erosion or runoff were avoided since the plots were flat, with a slope less than or equal to 2%. Partial nutrient balances were calculated as the difference between nutrient inputs and outputs in each farming system. The export of nutrients was calculated from the N, P and K content of all produce that left the plots. In the conventional farming systems all the biomass was taken from the

Table 4
Labour prices per working hour, and market prices of maize, beans and baby corn in the Central Highlands of Kenya.

Year	Labour (Ksh h^{-1})		Regular price of commodity (Ksh kg^{-1})								
	Location		Maize			Beans			Baby corn		
	Chuka	Thika	Chuka Market[a]	Thika Market[a]	Nairobi Market[b]	Chuka market	Thika market	Nairobi Market	Chuka market	Thika market	Nairobi market
2007	12.50	12.50	11.00	13.50	13.00	–	–	–	–	–	–
2008	15.00	15.00	23.00	22.00	20.00	50.00	50.00	51.00	18.00	18.00	NA
2009	15.63	18.75	26.00	25.00	28.00	44.00	50.00	50.00	15.00	15.00	NA
2010	16.88	25.00	13.00	17.00	18.00	–	–	–	–		–
2011	21.88	25.00	24.00	26.00	34.00	48.00	60.00	66.00	22.00	22.00	NA
2012	31.25	41.88	30.00	30.00	34.00	44.00	55.00	67.00	25.00	25.00	NA
Price of commodity with premium[c] (Ksh kg^{-1})											
2010			25.00	30.00	40.00	–	–	–			
2011			30.00	35.00	40.00	60.00	70.00	75.00	35.00	35.00	NA
2012			35.00	35.00	40.00	60.00	70.00	75.00	35.00	35.00	NA

[a] Wholesale annual average price from farmers and farmer group in Chuka and Thika.
[b] Whole sale annual average price from RATIN (http://www.ratin.net/http://www.ratin.net/).
[c] Organic price is a wholesale average annual price from Bridgees Organic shops, Kalimoni Organic Shops, Green dreams organic shop, Zucchini green shop. Premium considered only from 2010 (after conversion phase according to IFOAM). Conversion rate: 1Ksh = 0.015 USD (2007 & 2008), 1Ksh = 0.013 USD (2009), 1Ksh = 0.012 USD (2010, 2011, 2012) OANDA currency converter, 22.01.2014 NA, not available.

farm; whilst in the organic farming systems only the grains, cobs and husks were taken away, the rest of the biomass were recycled back into the soil through direct incorporation and composting (this was based on the common practices of conventional and organic farmers in the study area).

2.5. Statistical Analysis

Data validation at the site in Thika, revealed the necessity to exclude some of the low input plots. In Conv-Low, plot 12 was excluded between 2007 and 2010 due to a fallow effect which produced high yields, as was plot 15 which experienced erosion which led to crop failure in these years. In Org-Low plot 10 was excluded due to a fallow effect which produced excessive yields between 2007 and 2011. In the high input systems plots 9 and 20 were excluded from Conv-High, and plots 11 and 17 from Org-High in 2007 and 2008. This was also due to fallow effects which produced higher yields than the other plots. Agronomic and soil parameters were first checked for normal distribution using the Shapiro Wilk W Test. The Bartlett's test was selected to test the homogeneity of variances between conventionally and organically managed plots. Initially, crop yields were analysed across both locations for each of the three test crops across the years in all the cropping systems with linear mixed effect models using the statistics package 'JMP', version 5.0.1 (SAS Institute Inc., Cary, NC, USA). As site had a significant effect on the yields in most cases, two-way and three-way ANOVA were performed independently for each site and the two input levels (low and high). Analyses of variance (ANOVA) were performed at a significance level of ($P < 0.05$, 0.01 and 0.001), using linear mixed effect models with site, system and cycle as fixed effects, and replication and year as random intercepts. The cycle was included as a factor in the model to account for effects of the rotation on the same plot. The analysis was followed by a Tukey-Kramer multiple comparison test ($P < 0.05$) (Tukey's honestly significant difference HSD). A three-way ANOVA was performed for maize yields assessed under sole cropping at Chuka and Thika, for conventional and organic systems, in the first and second crop rotation (factors: site, system, cycle). A four-way ANOVA was performed for baby corn (under sole cropping), and maize/bean intercrop at Chuka and Thika for conventional and organic management systems in two consecutive years of the first and second crop rotations (the factors were site, system, cycle and year). Interactions between the factors were considered in all the ANOVA tests. With the effects of cycle and year being significant in most cases, the system effect was further tested separately in each cycle and year (cycle being equal to year in the case of sole cropped maize). Repeated analyses were applied for the total production costs, gross revenue or margins of maize or baby corn grown under sole cropping and maize-bean under intercropping.

3. Results

3.1. Effects of site and management systems on crop yields

Soil and weather:-the two sites showed differences in soil characteristics (Table 1), the amount and distribution of rainfall (Fig. 1) and the occurrence of dry spells (Table 5). At both sites the rainfall over the six main seasons was erratic and unevenly distributed. In Chuka, the rainfall between 2007 and 2012 ranged from 279 to 557 mm in the long rainy seasons and averaged 416 mm. Over 85% of all rainfall generally was received during the first 45 days after planting (DAPT) (i.e. when the maize reached knee height) (Fig. 1). At Thika during the long rainy season the rainfall ranged from 272 to 461 mm and the average was 322 mm (Fig. 1). Over 82% of all the rainfall was received during 50 DAPT in all the cropping seasons in Thika, except in 2011 where only 70% was received during 50 DAPT. Both Chuka and Thika had a similar frequency of total dry spells during the crop growth period in each long rainy season, except in 2009 and 2012 where Chuka recorded fewer dry spells than Thika (Table 5). In 2011 Thika also had fewer dry spells than Chuka. The highest frequency of dry spells of at least 5 days duration was recorded at Chuka in all six cropping seasons. By contrast Thika recorded the highest frequency of dry spells of at least 10 to 15 days in every cropping season.

Crop yields: Yields of maize grain and cobs of baby corn in the high input systems at Chuka were 60 and 40% higher than at Thika (Table 6). In the low input systems the maize yield at Chuka was 2 to 4 times higher than at Thika. The comparisons among cropping systems were consistent across the two sites as indicated by the non-significant difference for the site x system interaction for these crops (Table 6). There were, however, significant site x cycle interactions on the yields of baby corn or maize grain as a sole or a relay inter-crop in the high input systems, and yields of maize grain as the inter-crop in the low input systems (Table 6).

3.2. Crop yield under different management options

Sole cropped maize: in the low input systems at Chuka, maize grain yields in Conv-Low and Org-Low were similar in 2007 (in the 1st cycle,also referred to as the conversion period) and 2010 (in the 2nd cycle, also referred to as after-conversion in organic farming) (Table 7a). However, at Thika maize grain yields increased significantly from 2007 to 2010 ($P = 0.001$) by a factor of 3 in Conv-Low and a factor 7 of Org-Low. The yields in Conv-Low were 3 times higher than the yields in Org-Low in 2007 but this gap reduced to 1.5 times in 2010 (Table 7 a). At Chuka, there was no significant difference between the high-input systems (Conv-High and Org-High) on maize grain yields in 2007 and 2010 (Table 7b). Maize grain yields increased significantly ($P < 0.001$) from 2007 to 2010 in both Conv-High and Org-High. In this period Conv-High maize grain yields increased by 28%, whilst in Org-High yields increased by 54%. Maize grain yields at Thika – though exceptionally low – were nearly 4 times higher in Conv-High than in Org-High ($P < 0.05$) in 2007 (Table 7b). By 2010 the yields in Org-High increased and the difference between the two systems was no longer significant.

Maize intercropped with beans: in the two low-input systems there was no system effect on maize intercropped with beans at Chuka (Table 8a). Maize grain yields in both Conv-Low and Org-Low nearly doubled between the 1st cycle of 2008 and 2009 ($P < 0.001$). At Thika, no significant system effect on maize grain yields was observed when they were intercropped with beans, even though in 2008 maize grain yields from Conv-Low were 3 times higher than those of Org-Low (Table 8a). Maize grain yields in the 2nd cycle of Conv-Low were 2 to 10 times higher and those of Org-Low were 2 to 25 times higher ($P < 0.001$) than in the 1st cycle at both Chuka and Thika. Bean grain yields in Conv-Low and Org-Low were also similar.

Sole cropped Baby corn: whilst there were no differences in baby corn yields between the farming systems in individual years at both sites, as an average over all the years Org-High produced 8.6% higher ($P < 0.05$) baby corn yields than Conv-High in Chuka (Table 8b). At Chuka, baby corn yields during the 1st cycle (2008-2009) increased significantly ($P < 0.001$) by a factor of 3.9 in Conv-High and by a factor of 2.9 in Org-High. Cob yields of baby corn remained at around the same level during the 2nd cycle (2011-2012). At Thika, baby corn yields in 2008 were very low for both Conv-High and Org-High, but in 2009 they were exceptionally high ($P < 0.001$). In 2011 baby corn yields decreased ($P < 0.001$) in both systems and remained fairly stable the next year. It is worth

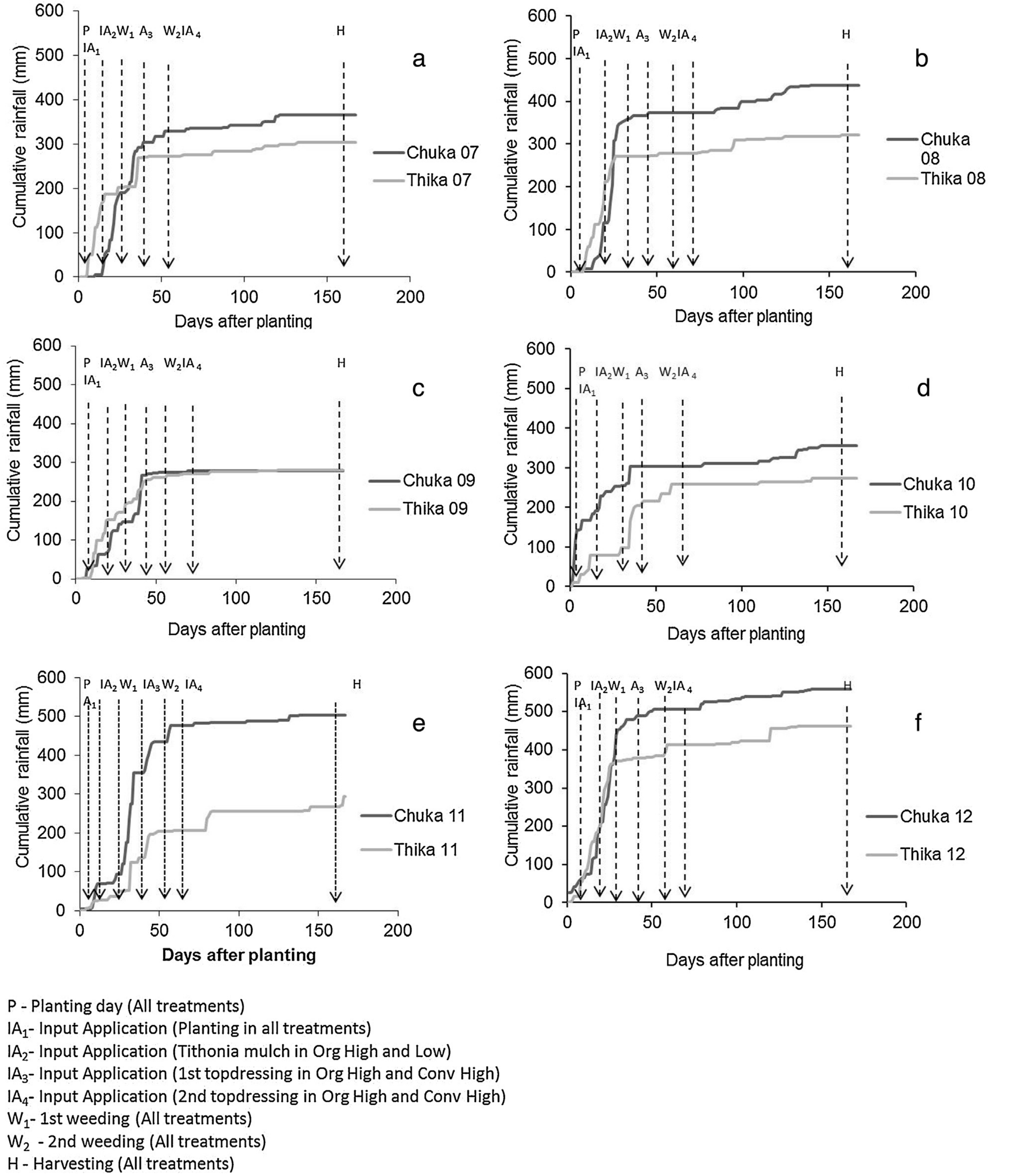

Fig. 1. Cumulative rainfall distribution during the crop growth period (March/April to August/September) for six consecutive years in the long term systems comparison trial sites at Chuka and Thika, Kenyan Central Highlands.

mentioning that on average, cobs of baby corn were harvested 17 times in Org-High as compared to 12 times in Conv-High at both Chuka and Thika. Also, whereas Conv-High showed high yields at the onset of harvesting and decreasing yields towards the end, Org-High showed lower yields at the beginning of harvesting that increased towards the end of the harvesting period.

3.3. An economic evaluation of conventional and organic farming systems

The production costs in Org-Low in 2007 were 12% higher ($P<0.001$) than those in Conv-low (Fig. 2a–b) at Thika and 17% higher at Chuka. In 2008 and 2009, however, the production costs

Table 5
Frequency with which dry spells exceeded 5, 10, 15 and 20 consecutive days during crop growth period in the long rainy seasons at the long-term systems comparison trial at Chuka and Thika, in the Central Highlands of Kenya.

Year	Occurence of dry spell									
	Chuka site					Thika site				
	>5 days	>10days	>15days	>20days	Total	>5 days	>10days	>15days	>20days	Total
2007	4	1	1	2	**8**	4	1	1	2	**8**
2008	4	2		1	**7**	2	1	3	1	**7**
2009	2	0	0	1	**3**	4	1	1	1	**7**
2010	4	0	0	2	**6**	2	1	1	1	**5**
2011	5	0	3	1	**9**	1	0	1	2	**4**
2012	1	0	1	1	**3**	4	1	3	0	**8**
Total	**20**	**3**	**5**	**8**		**17**	**5**	**10**	**7**	

Table 6
Effects of the sites on average maize and baby corn yields in conventional and organic farming systems at Chuka and Thika, in the Central Highlands of Kenya.

Cropping systems	Maize, sole cropping		Baby corn sole cropping	Maize intercropping
	High input system	Low input system	High input system	Low input system
Site	Yield (t ha^{-1})	Yield (t ha^{-1})	Yield (t ha^{-1})	Yield (t ha^{-1})
Chuka	5.01^{a}	3.13^{a}	9.93^{a}	3.74^{a}
Thika	3.12^{b}	1.25^{b}	7.1^{b}	0.91^{b}
ANOVAs of linear mixed effect models Source of variation	Prob>F			
Site	0.0001	0.0036	0.0005	0.0001
Cycle	0.0001	< 0.0001	0.7424	< 0.0001
Site x cycle	0.0001	0.0192	0.03	0.4293
System	0.9595	0.3221	0.0631	0.9748
Site x system	0.1968	0.0839	0.1339	0.9032

Significant differences ($P < 0.05$) between sites are indicated by the letter a and b.

between the two low input systems were around the same at both sites. With the inclusion of certification costs from 2010 to 2012, the production costs in Org-Low at Chuka in 2010 were 100% higher than the costs in Conv-Low and those at Thika 31% higher ($P < 0.001$). This huge difference however reduced in 2012, with Org-Low recording 10% higher production costs than Conv-Low in Thika and 47% higher production costs in Chuka. The production costs in 2007 of maize in Org-High were 36% higher than in Conv-

Table 7
a-b Mean grain yields (13% dry matter) of maize grown under sole cropping/relay-intercropping in high and low input conventional and organic farming systems at Chuka and Thika in the Central Highlands of Kenya.

	a)Maize						b)Maize					
	Low input systems, sole cropping						High input systems, sole cropping/relay intercropping					
	Chuka			Thika			Chuka			Thika		
Farming system	(t ha^{-1})[w]	sem[x]	n[y]	(t ha^{-1})	sem	n	(t ha^{-1})	sem	n	(t ha^{-1})	sem	n
Cycle 1(2007)[u]												
Conventional	2.56^{a}	0.34	4	0.73^{a}	0.09	3	4.30^{a}	0.36	4	0.77^{a}	0.23	3
Organic	3.13^{a}	0.32	4	0.23^{b}	0.03	4	4.05^{a}	0.26	4	0.21^{b}	0.08	4
Cycle 2 (2010)												
Conventional	3.54^{a}	0.58	4	2.36^{a}	0.23	3	5.49^{a}	0.48	4	5.86^{a}	0.27	5
Organic	3.30^{a}	0.59	4	1.70^{b}	0.24	4	6.23^{a}	0.26	4	5.81^{a}	0.23	5
Average (cycle 1 & 2)[v]												
Conventional	3.05^{a}	0.36	8	1.55^{a}	0.42	6	4.89^{a}	0.36	8	3.26^{a}	0.95	8
Organic	3.22^{a}	0.31	8	0.97^{b}	0.30	8	5.14^{a}	0.44	8	2.99^{a}	0.99	9
ANOVA (Cycle 1 & 2)												
Source of variation	P value		Df[z]	P value		Df	P value		Df	P value		Df
System (S)	0.627		1	0.010		1	0.423		1	0.305		1
Cycle (C)	0.120		1	<0.001		1	<0.001		1	<0.001		1
S x C	0.250		1	0.278		1	0.129		1	0.397		1

Significant differences ($P < 0.05$, 0.001) between farming systems are indicated by the letter a and b.
[u] ANOVA per cycle: One-way analysis of variance including the factor System.
[v] ANOVA both cycles: Two-way analysis of variance including the factors System and Cycle.
[w] Turkey-test: Values not connected with the same letter differ significantly ($P < 0.05$).
[x] Sem = standard error of means.
[y] n = number of observations.
[z] Df = degree of freedom.

Table 8
a-b Mean cob yields (fresh matter) of baby corn grown under sole cropping/relay-intercropping and maize grain yields (14% dry matter) grown under intercropping in high and low input conventional and organic farming systems at Chuka and Thika in the Central Highlands of Kenya.

		a) Maize and Beans								b) Babycorn			
		Low input systems, intercropping								High input system, sole cropping/relay cropping			
		Chuka				Thika				Chuka		Thika	
		Maize		Beans		Maize		Beans		Babycorn		Babycorn	
	Farming system	(t ha^{-1}) [w]	sem [x]	(t ha^{-1})	sem	(t ha^{-1})	sem	(t ha^{-1})	sem	(t ha^{-1})	sem	(t ha^{-1})	sem
Cycle 1(2008 & 2009) [t]	Conventional									8.52^{a}	2.02	6.40^{a}	2.19
	Organic									8.90^{a}	1.7	6.20^{a}	2.18
Year 2008 [u]	Conventional	2.48^{a}	0.77	0.23^{a}	0.09	0.21	0.12	na	na	3.45^{a}	1.15	0.31^{a}	0.01
	Organic	1.98^{a}	0.55	0.25^{a}	0.10	0.07	0.02	na	na	4.50^{a}	0.71	0.14^{a}	0.05
Year 2009	Conventional	4.23^{a}	0.76	1.03^{a}	0.14	0.14	0.09	0.18^{a}	0.07	13.60^{a}	0.69	12.23^{a}	0.28
	Organic	3.77^{a}	0.27	0.82^{a}	0.20	0.14	0.01	0.20^{a}	0.08	13.30^{a}	0.16	12.00^{a}	0.32
Cycle 2 (2011 & 2012)	Conventional									10.51^{a}	0.48	7.63^{a}	0.19
	Organic									11.78^{a}	0.42	7.93^{a}	0.2
Year 2011	Conventional	3.92^{a}	0.56	0.62^{a}	0.13	2.16	0.49	0.21	0.10	10.73^{a}	0.22	7.63^{a}	0.21
	Organic	5.48^{a}	0.39	0.73^{a}	0.24	2.75	0.63	0.32	0.12	11.03^{a}	0.18	8.40^{a}	0.19
Year 2012	Conventional	4.33^{a}	1.07	0.70^{a}	0.17	1.12	1.12	0.11	0.06	10.29^{a}	0.99	7.63^{a}	0.34
	Organic	3.56^{a}	0.73	0.78^{a}	0.11	0.84	0.84	0.11	0.06	12.52^{a}	0.64	7.46^{a}	0.19
Average (cycle 1 & 2) [v]	Conventional									9.52^{b}	1.03	6.99^{a}	0.94
	Organic									10.34^{a}	0.92	7.04^{a}	0.94
ANOVA (Cycle 1 & 2)	Source of variation	P value	Df	P value	Df	P value	Df	P value	Df	P value	Df	P value	Df
	System (S)	0.905	1	0.098	1	0.913	1	0.106	1	0.042	1	0.774	1
	Cycle (C)	0.012	1	0.28	1	<0.0001	1	0.854	1	0.659	1	0.8	1
	Year [C]	0.0004	3	<0.001	3	0.0001	3	<0.0001	3	< 0.01	2	<0.001	2
	S x Y [C]	0.088	3	0.733	3	0.302	3	0.07	3	0.115	2	0.127	2

Significant differences (P < 0.05, 0.001) between farming systems are indicated by the letter a and b.
[t] ANOVA per cycle: Two-way analysis of variance including the factors System and Year.
[u] ANOVA per year: One-way analysis of variance including the factor System.
[v] ANOVA both cycles: Three-way analysis of variance including the factor system.
[w] Tukey-test: Values not connected with the same letter differ significantly (P < 0.05).
[x] sem = standard error of means, Df = degree of freedom; na, not available.

High at Thika, and 65% higher at Chuka ($P < 0.0001$) (Fig. 2a–b). In 2008 the difference in costs reduced to 1.6% in Thika and 53% in Chuka. In 2009 the cost in Conv-High was 7% higher ($P < 0.05$) than Org-High in Chuka and 17% higher in Thika. With the inclusion of certification costs between 2010 and 2012 the production costs in Org-High exceeded those of Conv-High, by 2.4 times in Chuka and by 89% in Thika ($P < 0.0001$). This huge difference, however, reduced in 2012, with Org-High recording 41 and 44% higher ($p < 0.001$) costs than in Conv-High at Chuka and Thika.

A similar trend was observed when production costs were calculated for the regional market (in Nairobi, see Annex 2a-b, supplementary sheet). However, purchasing inputs from, and transporting farm produce to, Nairobi's markets increased the production costs slightly above those incurred when buying and selling locally at Chuka and Thika. On the average the production costs of Conv-High in 2007 were 1.7 times higher ($P < 0.0001$) than for Conv-Low at Chuka and 2.3 times higher ($P < 0.0001$) at Thika. In 2012 they were 1.8 to 2.3 times higher. Similarly, the average production costs for Org-High in 2007 were 2.5 times higher than for Org-Low at Chuka and 2.9 times higher at Thika. In 2012, when certification costs were also a factor, the costs were 1.8 and 2.5 times higher at the two sites ($P < 0.0001$).

The cumulative total revenue obtained for selling produce at local and regional markets is shown in Figs. 3a–d and Annex 3a-d of the supplementary sheet. There was no significant difference in the total revenue obtained from Conv-Low and Org-Low or from Conv-High and Org-High when selling the produce at a regular prices on either the local (Fig. 3a & c) or regional markets (Annex 3a & c). The total revenue obtained from Org-Low was 1.2 to 1.4 times higher than that obtained from Conv-Low. Between 2009 and 2012 the total revenue from Conv-High and Org-High was higher ($P < 0.05, 0.001$) than the total revenue from Conv-Low or Org-Low at both sites. With a premium price for organic produce from 2010 onwards the total revenue obtained from Org-High in 2011 and 2012 was 1.4 to1.5 times higher ($P < 0.05, 0.0001$) than from Conv-High at both sites (Fig. 3b & d). The cumulative gross margins (profits) for the different farming systems are shown in Figs. 3e–h and Annex 3 e-h, supplementary sheet. Except in 2007, when the profit from Conv-High was 2.1 to 3.8 higher ($P < 0.0001$) than from Org-High (under both local and regional markets), there was no significant difference in the profit made from Conv-High and Org-High when the organic produce was sold at regular price (Figs. 3e & g, Annex 3e & g). With the premium price on organic produce from 2010 to 2012, the profit obtained in 2011 from Org-High on the local market was 1.3 times higher than the profit from Conv-High at Chuka and 3.2 times higher at Thika ($P < 0.001$) (Figs. 3f & h). In 2012 the profit from Org-High was 1.5 times higher than that from Conv-High at Chuka and 4.1 times higher at Thika. Similarly, the profit from Org-High in 2011 on the market in Nairobi was 40% higher than the profit from Conv-High at Thika and 60% higher at Chuka ($P < 0.01, 0.001$) (Annex 3f & h). In 2012 the profit from the same market for Org-High was 60% and 90% higher than for Conv-High. Whereas there was a marginally larger profit from Conv-High than Conv-Low in 2012 at the Nairobi market, when organic

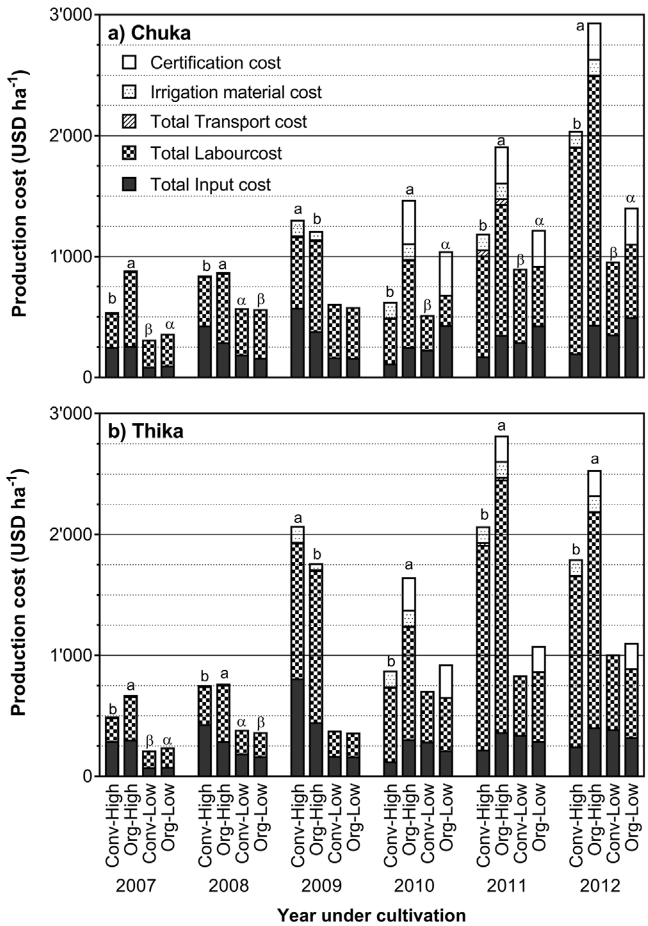

Fig. 2. a–b: Production costs for conventional and organic farming systems in the long-term system comparison trials at Chuka and Thika, Central Highlands of Kenya.

produce was sold at a premium the profit from Org-High was significantly higher ($P < 0.05$, 0.001) than the profit from Org-Low in all the markets. There was no appreciable benefit in selling produce grown under any of the systems at Thika at either market. On the local market at Chuka, the seasonal benefit cost ratio (BCR) for Conv-Low was −0.3 in 2007 and 1.2 in 2012. In 2009 it reached 2.2. The BCR for Org-Low started at 0.5 in 2007 and increased to 2.3 in 2009, before falling back again to 0.2 in 2010 and 0.5 in 2012. In the high input system, the BCR for Conv-High ranged from 0.1 to 0.5 between 2007 and 2012, except in 2011 when it was 1.4 (Fig. 4a–b). In Org-High, the seasonal BCR (with no premium price) was −0.2 in 2008 and 1.2 in 2009, but then declined to −0.1 in 2010 and 0.4 in 2012. On the regional market the seasonal BCR for produce from the Conv-High system at Chuka ranged from 0.3 in 2007 to 1.0 in 2011 (Annex 4a-b, supplementary sheet). In Org-High the BCR ranged from 0.4 in 2007 to 1.1 in 2011. At Thika, the BCR for all the systems under both local and regional markets was less than 1 (Figs. 4c & d, Annex 4a & d supplementary sheet).

3.4. The effect of farming systems on nutrient export and partial nutrient balances

The cumulative nutrient inputs and exports from the different farming systems are shown in Fig. 5. At the end of six years, 540 and 562 kgN ha^{-1}, 337 and 901 kgK ha^{-1} were exported from Conv-High, more ($P < 0.05$) than the amount exported from Org-High (147 and 224 kgN ha^{-1}; 94 and 149 kgK ha^{-1}). On average, 135 and 138 kg N ha^{-1}, 15 and 13 kg P ha^{-1}, 113 and 192 kg Kha^{-1} were exported seasonally from Conv-High at Thika and Chuka, significantly more than the 37 and 42 kg N ha^{-1}, 5.3 and 5.7 kg P ha^{-1}, 31 and 36 kg K ha^{-1} exported seasonally from Org-High. In Conv-Low, 48 and 119 kg N ha^{-1}, 3 and 10 kg P ha^{-1}, 38 and 93 kg K ha^{-1} were exported seasonally compared to 23 and 55 kg N ha^{-1}, 3 and 8 kg P ha^{-1}, 6 and 22 kg K ha^{-1} exported seasonally from Org-Low (Table 9). At Chuka, similar N and P were exported from Conv-Low and Conv-High, whilst higher N and P were exported from Org-Low compared to Org-High. In contrast, at Thika, Conv-High exported higher N and P compared to the other systems. In Conv-Low, the K exported from both sites and the N from Chuka was significantly higher than those exported from Org-Low. With the exception of N at Chuka, Org-High showed positive and higher ($P < 0.05$) partial N and K balances at both sites than the other three systems (Fig. 6). All the systems showed a positive P partial balance with the partial P balance in the high input systems being higher ($P < 0.05$) than in the low input systems. Similarly, the P balance in the conventional systems was higher ($P < 0.05$) than the P balance in organic systems.

4. Discussion

4.1. Effects of site, cropping systems and their interactions with the environment on crop yields

There was no discernable interactive effect between site and farming systems on crop yields (Table 6). There was however, a significant ($P < 0.0001$, 0.0005) site effect on crop yields in all the different cropping systems (Table 6) which can be attributed to the differences in environmental (weather and soil) conditions at the two sites. At Thika the initially low soil fertility status (Table 1), unfavourable weather conditions (low rainfall, uneven distribution and moisture stress due to intermittent and prolonged dry spells) (Fig. 3, Table 5), the late introduction of irrigation (2009) and scarcity of irrigation water in 2011 (due to a broken overhead tank) and 2012 (due to a shortage of water supply to the Thika community) were the major site-specific factors accounting for the lower yields of all crops under all systems. Water stress induced by low rainfall accounted for 12 and 20% of the variation in yields of the maize intercropped with beans in the unirrigated low input systems. The site at Thika had a lower soil pH, less organic carbon (org-C), total N, and very low available P and cation exchange capacity (CEC) compared to Chuka (Table 1). These factors all affect nutrient availability to crops, their growth, nutrient use efficiency and ultimately yields (Subede and Ma, 2009; Westerman et al., 1999).

4.2. The effect of farming systems on crop yields

Sole cropped maize: at Chuka in 2007 all four systems achieved similar maize yields (Table 7a-b). This is in line with the results of Lotter et al. (2003), who in the early years of their trials in Pennsylvania (US) reported that organic and conventionally managed systems gave similar maize yields, as well as Mucheru-Muna et al. (2014) in Meru South in the Central Highlands of Kenya. The similarity in maize yields between the systems during the 1st cycle (2007) could be attributed to initial inherently high soil fertility (Table 1) and relatively abundant and fairly evenly distributed rainfall during the cropping seasons (Fig. 1a). The initial soil pH, CEC, org-C, N and available P were similar for both sites and, together with the relatively high rainfall (318-335.5 mm) it's fairly even distribution during the critical growth period 46 to 80 days after planting (DAPT) should have enhanced nutrient availability for plant uptake (especially P and K, Table 9a-b), growth and development in all the systems. The fairly high maize grain yields during the 2nd cycle in 2010 (Table 7a-b) can be attributed to the effect of increased soil nutrient inputs

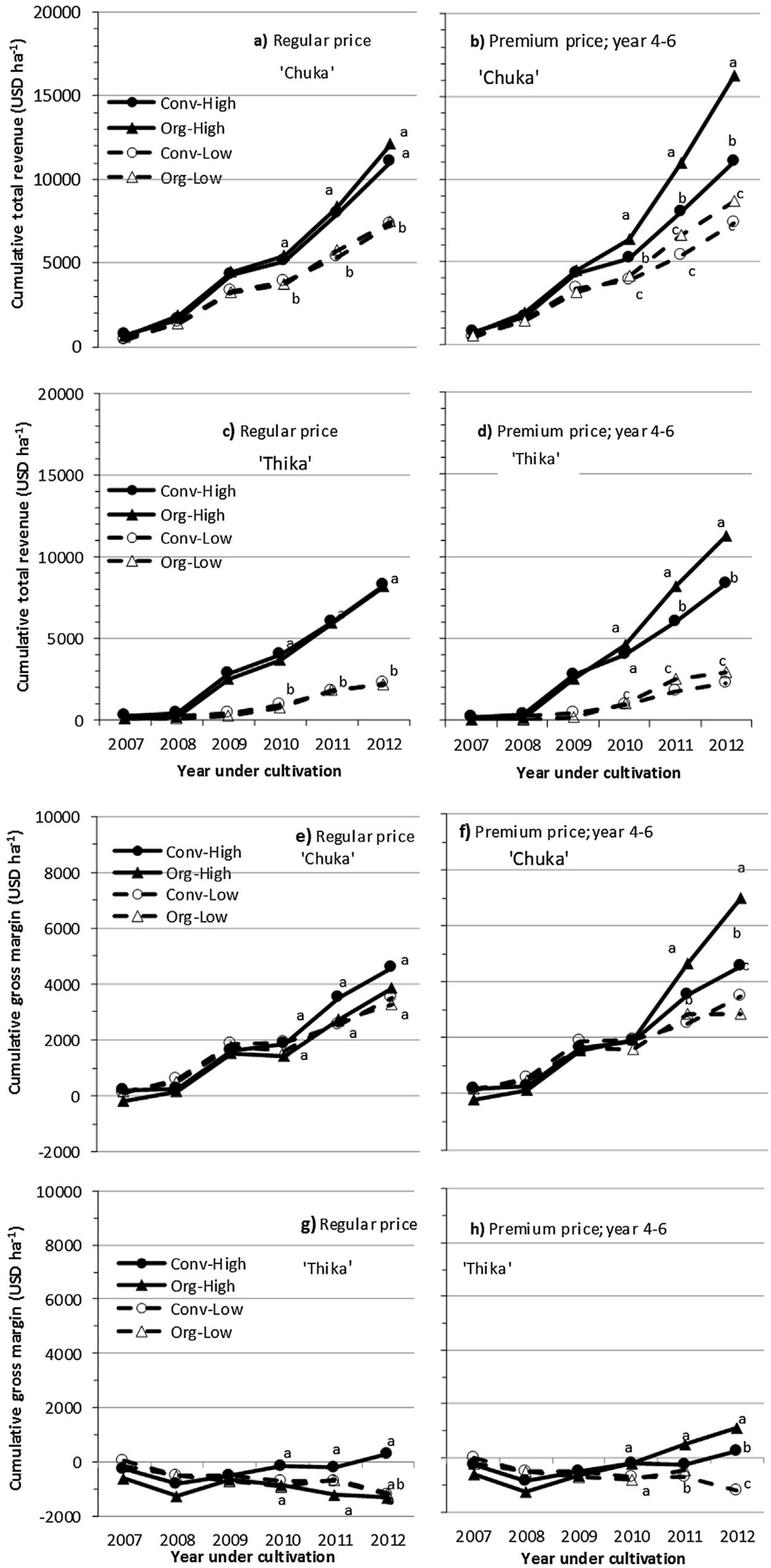

Fig. 3. Total revenue (a–d) and profit (e–f) obtained in the local market from conventional and organic farming systems in the long-term system comparison trials at Chuka and Thika, Central Highlands of Kenya.

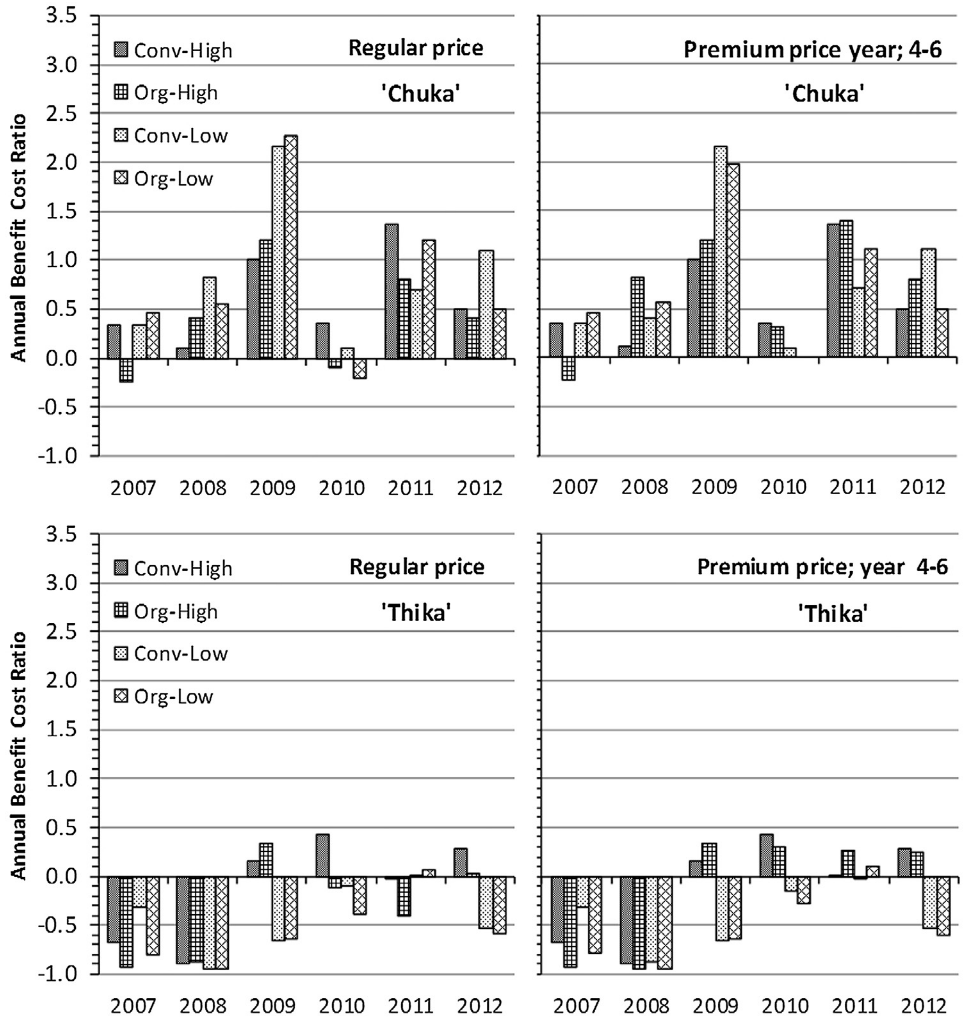

Fig. 4. Benefit cost ratio obtained from conventional and organic farming systems in the local markets at Chuka and Thika, Central Highlands of Kenya.

(Fig. 5) on soil fertility (data reported separately) as well higher rainfall and better distribution (which would have had more of an effect on the low input systems which had no access to irrigation, Fig. 1d). By contrast at Thika the maize yields in 2007 for the two organic systems were 3 to 4 times lower ($P = 0.001$) than in their respective conventional counterparts (Table 7a-b). This is in line with the observations of Clark et al. (1999) who, in an eight-year study of sunflower-tomato-corn-wheat/bean rotation in California (US), found corn yields from the organically managed system to be 1.2 times lower than those in conventional systems in the first year. Kibunja (2012) who used a continuous maize-beans rotation in the first six years of cultivation in the Kabete long term trial in Kenya, reported maize crops from the organically managed system (FYM) to be about 50% lower than those from the conventionally managed systems (when applied as NP or NP + FYM). In our trial we applied almost equal amounts of nutrients to the conventional and organic systems but irrigation in the high input systems for maize was only introduced in 2009. The most likely explanation for the two organic systems having significantly lower (3 to 4 times lower $P = 0.001$) maize grain yields than their conventional ones in 2007 at Thika is a slower take up of nutrients from organic fertilisers than from conventional ones (unpublished data from on-going PhD study). The reasons given to explain the high yields at Chuka in 2010 also apply for the higher maize grain yields in all systems in 2010 at Thika.

Maize intercropped with beans: maize grain yields in both Conv-Low and Org-Low at Chuka doubled between 2008 and 2009 and then stayed fairly stable until 2012 (Table 8a). This can be attributed to improvements in soil management practices and the effects of the crop rotation. The cropping patterns in the rotation, i.e. maize intercropped with beans in 2008, 2009, 2011 and 2012, and the cultivation of other grain legumes in the 2nd season of 2008 and 2011 (Table 2) contributed to improving the soil fertility (data reported separately). The incorporation and mineralisation of decaying legume leaves and root biomass increased the availability of mineral-N to maize crops (Adeboye et al., 2005; Evans et al., 2001). However, the fairly low maize grain yields in Org-Low in 2012 could not be explained (Table 8a). The potential of cereal-cowpea- and/or legume rotations to significantly increase yields of cereal crops has been documented by several authors (Adeboye et al., 2005; Rao and Mathuva, 2000; Sakala et al., 2004). At Thika, relatively low maize yields were obtained in 2008 and 2009 in both Conv-Low and Org-Low and this can be attributed to the effect of the weather (as explained in 4.1). Moisture stress also affected the flowering and pod filling stages of beans, thereby limiting yields, hence the exclusion of bean data in the 2008 yield calculation. Some of the maize grain yields in our trial under Conv-High and Conv-Low (0.73-5.49 t ha^{-1}) and Org-High and Org-Low (0.23-6.25 t ha^{-1}) at Chuka and Thika sites were below the values (1.6-6.5 t ha^{-1}) reported by the Embu long term trial (1993–2005) and

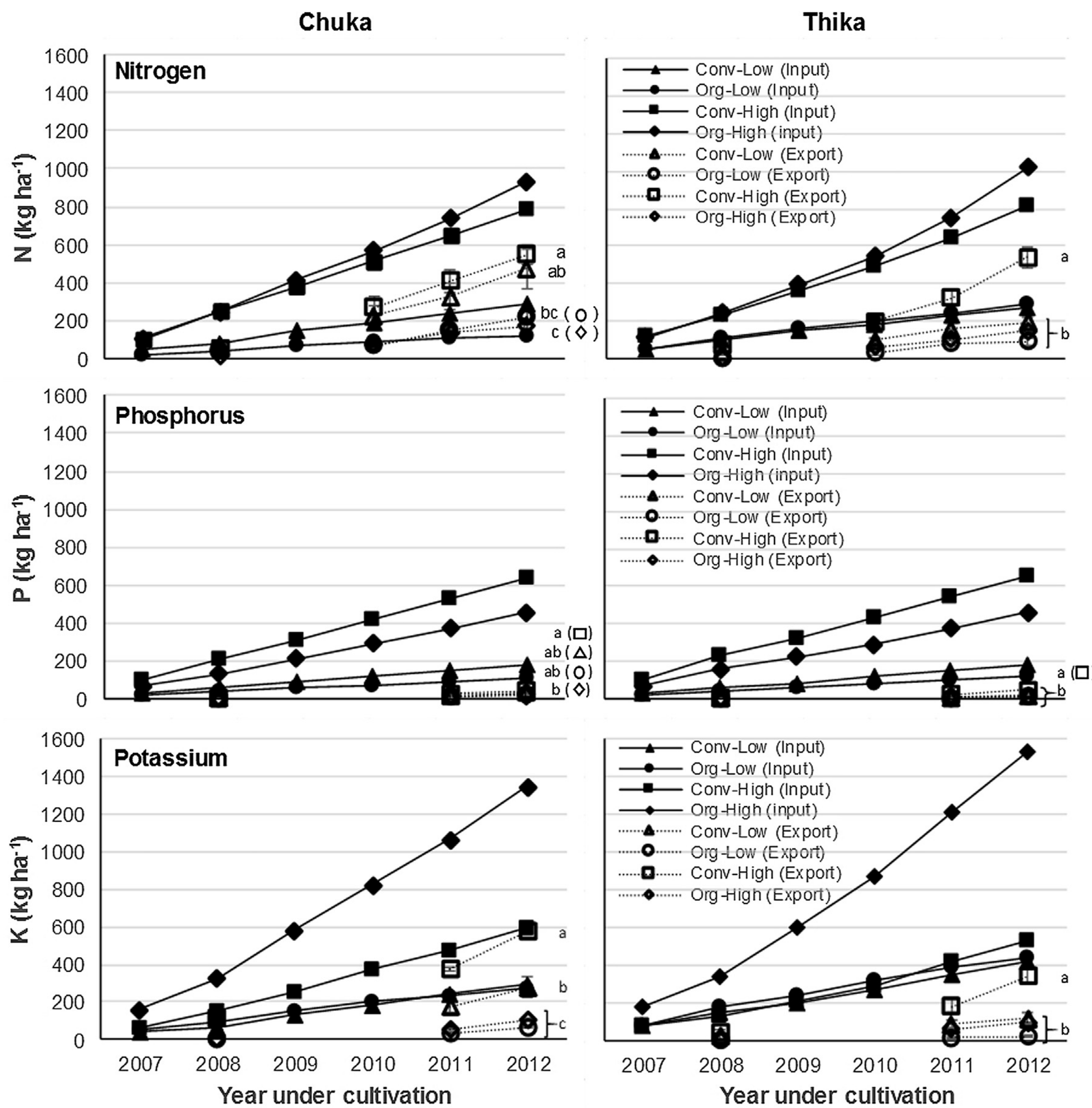

Fig. 5. Cumulative nutrient input and export for nitrogen, phosphorus and potassium in the first seasons of 2007 to 2012 in the long term system comparison trials at Chuka and Thika. (Significant differences ($P < 0.05$) are indicated by the letters a, b, c and d).

Table 9
Average seasonal nutrient export and percentage of nutrient input exported in the Long Term System Comparison Trials at Chuka and Thika in the Central Highlands of Kenya.

Site	Farming system	N export		P export		K export	
		Seasonal Average	Express as percentage of nutrient input	Seasonal Average	Express as percentage of nutrient input	Seasonal Average	Express as percentage of nutrient input
		($kg N ha^{-1}$)	(% N)	($kg P ha^{-1}$)	(% P)	($kg K ha^{-1}$)	(% K)
Chuka	Conv-High	137.7[a]	101[a]	13.2[a]	12[b]	192.2[a]	178[b]
	Org-High	42.4[b]	26[b]	5.7[b]	7[b]	35.5[c]	14[c]
	Conv-Low	118.9[a]	260[a]	10.2[ab]	4[a]	92.6[b]	246[a]
	Org-Low	55.1[b]	302[a]	8.2[ab]	49[a]	22.2[c]	58[c]
Thika	Conv-High	134.9[a]	91[ab]	15.2[a]	13	112.3[a]	115[a]
	Org-High	36.8[a]	19[c]	5.3[b]	6	31.3[b]	9[c]
	Conv-Low	48.0[b]	120[a]	2.8[b]	10	38.3[b]	53[b]
	Org-Low	23.5[b]	55b[c]	3.2[b]	17	5. 9[b]	9[c]

NB: Significant differences ($P < 0.05$) between farming systems are indicated by the letters a, b & c.

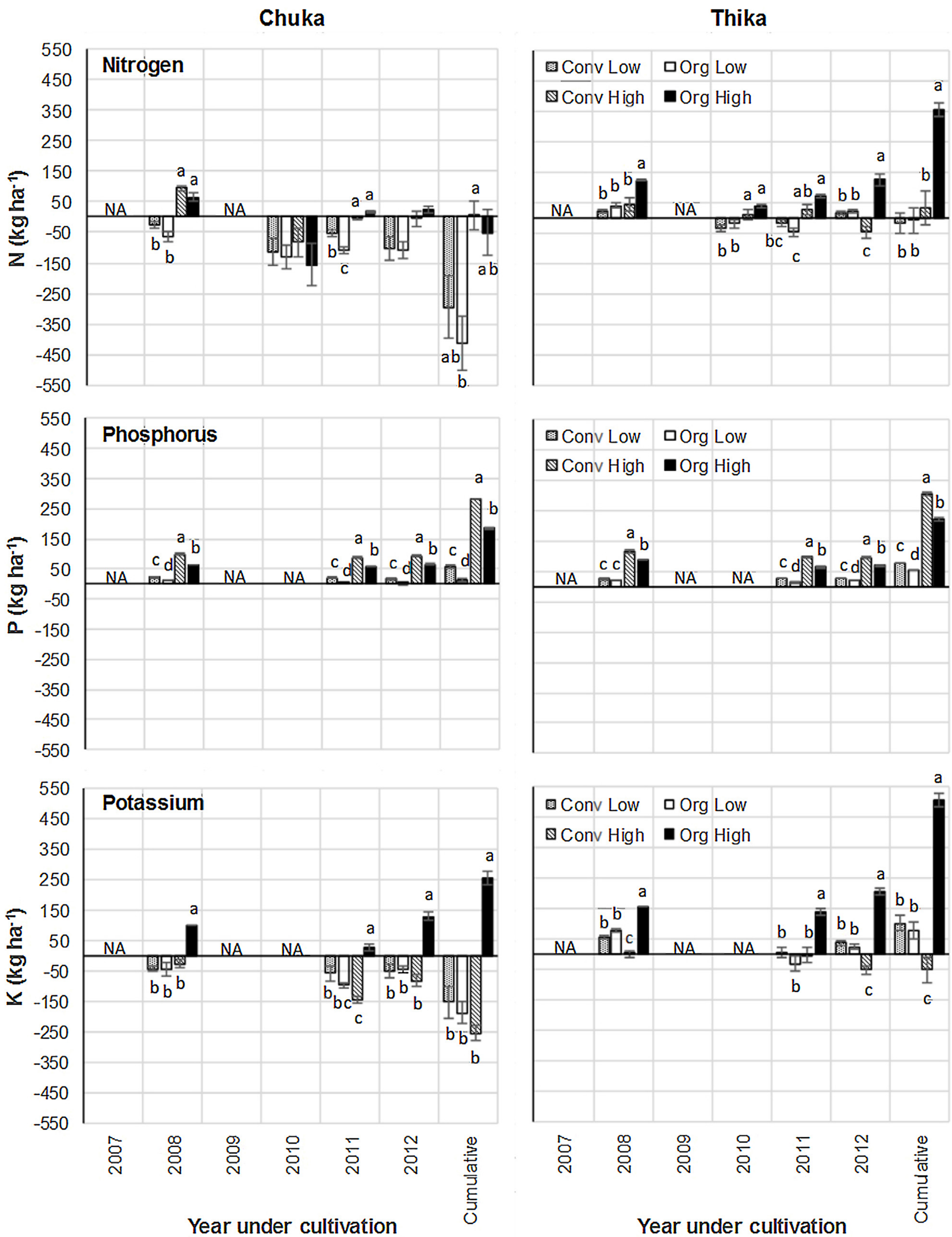

Fig. 6. Cumulative nutrient balances for nitrogen, phosphorus and potassium in the first seasons of 2007 to 2012 in the long term system comparison trials at Chuka and Thika. (NA, data for cropping year is not available due to loss of grain samples as a result of relocation of the laboratory. Significant differences (P < 0.05) are indicated by the letters a, b, c and d).

the Kenyan Agriculture Research Institute's (KARI) long term trial (1976-to date) at the National Agriculture Research Laboratories (NARL) in Kabete (Bationo et al., 2012; Kibunja et al., 2012).

Sole cropped Baby corn: cob yields of baby corn in Org-High at Chuka and Thika were similar to the yields in Conv-High (Table 8b). This result contrasts with the experiences of Saha et al. (2007) who reported that conventionally managed plots produce significantly higher yields of baby corn cobs than organic ones. The disparity between these two results may be due to improved nutrient availability (data reported separately) and uptake (especially N and P in 2011 and 2012, Table 12, supplementary sheet) leading to high yields of cobs per unit area in Org-High at Chuka in 2008, 2011 and 2012 (Table 8a-b). This may also explain the observed higher frequency of prolonged harvests in Org-High than in Conv-High. Differences in the amount and patterns of N release by organic inputs and synthetic fertilisers (Adamtey, 2010) may also explain why Conv-High obtained higher yields at the beginning of harvest than Org-High. In 2008 the two high input systems at both sites recorded lower cob yields of baby corn than they did in subsequent years (Table 8b). This can largely be attributed to an erratic distribution of rainfall (Fig. 1b), as the irrigation facilities were not yet installed (Table 3) and a crop rotation effect (Table 2). The cropping pattern and rotation effect also account for the significant increase ($P < 0.01$) in cob yields of baby corn in 2009 (Table 8b) at both sites. In the rotation maize and cabbage were planted in the 1st and 2nd seasons of 2007 before baby corn in the 1st season of 2008 (Table 2). Maize and cabbage are both crops with high nutrient demand (Muriuki et al., 2002; Schnier et al., 1997) and are likely to have removed more nutrients from the soil prior to the baby corn being cultivated. As such in 2008 the baby corn would have been more dependent on applied nutrients. In the organic system less than 10% of the total N applied from compost would have been available to the first crops (Adamtey, 2010). Conversely, the relay intercropping of maize with *Mucuna* in the 1st season of 2008, followed by legumes (French beans) in the 2nd season, would have added available N to the soil for the following crop of baby corn in 2009 (Wortmann et al., 2000; Flores-Sanchez et al., 2013). This, together with the introduction of supplementary irrigation in the second season of 2008, was expected to increase cobs and kernel yields, which did occur in 2009 (Adamtey, 2010; Hammad et al., 2011). Osie-Bonsu and Buckles, (1993), Hauser and Nolte (2002) have estimated that when *Mucuna puriens* is grown as an intercrop or as sole crop, it provides an equivalent of 87–171 kg N ha^{-1} (through N fixation) and 138–218 kg N ha^{-1} (through N retained in residues) to the succeeding crop of maize. Bationo et al. (2011) also reported that, with efficient soil fertility management, cowpea can fix up to 88 kg N ha^{-1} and this can increase the nitrogen use efficiency of the succeeding cereal crop from 20% under continuous cereal monoculture to 28%. The cob yields of baby corn obtained from Conv-High and Org-High were within the values reported by Golada et al. (2013), Lone et al. (2013) and Muthukumar et al. (2005) in India. At both sites the productivity of baby corn was similar in both Conv-High and Org-High.

4.3. An economic evaluation of conventional and organic farming systems

4.3.1. Production costs

The higher production costs incurred in producing maize and baby corn in Org-High than in Conv-High (Fig. 2a–b and Annex 2a–b) is in contrast with the experiences of Delbridge et al. (2011) who reported similar production costs between the two types of systems in a 4-year corn-soybean/alfafa crop rotation. In a 10 year trial in Minnesota (US), Mahoneya et al. (2004) reported the organic system to have lower production costs. The disparity in the results from our case can mainly be attributed to both high labour costs and the subsidies for synthetic fertilisers that were offered by the Kenyan Government in 2010 (Sheahan et al., 2013). The labour costs of producing maize and baby corn in Org-High were higher every year ($P < 0.05$) than in Conv-High at both sites (Fig. 2a–b, Annex 2a–b) as the preparation and use of organic materials and the management of organic farms was more labour intensive. In the organic system there were higher labour costs for land preparation, mulching, Tithonia tea preparation, composting and more frequent weeding. In Conv-High the labour costs were associated with land preparation, weeding, and the application of pesticides. These results are consistent with those of Kipsat et al. (2004) who reported higher labour costs (75% of the total production cost) in western Kenya when using organic inputs and technologies rather than synthetic inputs (61% of the total production in conventional farming). The high production costs associated with the additional labour input required for organic farming imply the need to look for ways to reduce labour costs, particularly those associated with producing and applying organic fertilisers. The development of simple machinery and techniques for producing and applying organic inputs that can be used by both small and medium-to-large scale farmers could help relieve farmers of the high labour investments needed in organic production. Alternatively, the establishment of community-level compost-making facilities in areas close to organic farms that could supply high quality compost or organic fertilisers at an affordable cost is another potential solution for organic growers.

4.3.2. Gross margin (Profit)

Despite the higher production costs in the high and low input organic systems, Org-High achieved similar gross margins (profits) per hectare at Chuka to its conventional counterpart between 2008 and 2012 when producing maize and baby corn (Fig. 3e, & Annex 3e of supplementary sheet).The same held true for Org-Low when maize was inter-cropped with beans at Chuka. This indicates that, in the second year of conversion and thereafter, organic farming (with produce sold at a regular price) yielded similar profits as its conventional counterpart. This contradicts the reports of Clark et al. (1999) and Setboonsarng et al. (2008) who argue that, in the absence of price premium, the returns to organic production system are lower than those to conventional production systems and corroborate the assertion of Welsh (1999) and Mahoneya et al. (2004) that price premiums are not always necessary for organic systems to be competitive with conventional systems. Delbridge et al. (2011) reported on a 4 year corn-soybean/alfafa crop rotation organic input system (without premium prices) that had a similar net return to chemical input systems, but when a premium was available for the organic produce, the organic system yielded considerably higher net returns than the conventional system. This is corroborated by our findings. In 2011 and 2012 organic produce from both sites was able to achieve an average premium price of 20-50% on the local and regional markets (Table 4). This in turn meant that Org-High was able to achieve a 1.3 to 4.1 times higher ($P < 0.01$) gross margin (profit) than Conv-High. This provides a strong indication that organic high input systems can be more profitable than conventional high input systems when the premium price is available. In our trials this occurred between the fifth and sixth year of organic cultivation. IFOAM (2013) has also reported that farmers that engaged in certified organic export production in East Africa make significantly more profit than those engaged in conventional production. These results and trends will need regular monitoring in the coming years to see whether they continue. At Thika, all the farming systems had negative gross margins (losses) from 2007 to 2009 when selling produce at regular price (Figs. 3g, & Annex 3 g of supplementary sheet). This can be attributed to poor crop performance in all the systems

(Tables 7 and 8), as explained in Section 4.1. This shows that maize cultivation, in both organic and conventional systems is not profitable in places such as Thika, with inherent poor soil fertility and low rainfall. Attention should be focused on searching for other crops that thrive well and provide good yields and high returns dividends under such conditions, so as to secure the livelihoods of small-scale farmers. The adoption of no-till in such low rainfall areas is one potential option to improve soil productivity in all farming systems (Shrestha et al., 2013).

4.3.3. Benefit Cost Ratio

The negative BCR obtained in Chuka in 2007 in Org-High (Fig. 4a & Annex 4a) can be attributed to high labour costs (Annex 5a). The labour costs in Org-High were twice those in Conv-High and 2.3 and 2.7 times those in Conv-Low and Org-Low. In 2008 and 2009 the price of maize rose (Table 4) and, in 2009, this was coupled with an increase in yields of baby corn, maize and beans (Table 8a-b). This led to all the systems achieving a positive BCR (i.e > 1) in 2009. In 2010 maize yields were again high (Table 7a-b) but the price of maize fell and this offset the effect of yield increases on BCR, leading all the systems (except Conv-High) to experience a negative BCR. The sharp rise in the price of maize in 2011 and 2012 (Table 4) may well account for the high BCR for all systems in those years (Fig. 4a). Premium prices also account for the high BCR in the organic systems in 2011 and 2012 (Fig. 4b). These results show that fluctuations in market prices and yields of produce are among the major determinants for obtaining a higher or lower (or even positive and negative) BCR from any agricultural production system and that when premium prices are available, organic farming systems can generate a higher BCR. However, the very low BCR at Thika, never more than 0.5 (Fig. 4c–d, Annex 4c-d of supplementary sheet) for all the farming systems (with and without premium prices) implies that sites with low or erratic rainfall and initially low inherent soil fertility are not suitable for the production of baby corn and maize as sole crops or maize inter-cropped with beans and that such activities may incur more production costs than the benefits they bring.

4.4. The effect of farming systems on nutrient export and partial nutrient balances

There was higher ($P < 0.05$) cumulative N and K export from conventional systems than from organic systems (Fig. 5). The average seasonal loss of N, P and K from Conv-High was also higher ($P < 0.05$) than the loss from Org-High (Table 9). This can be attributed to the total removal of harvestable crop biomass from the conventional systems for use as household fuel, feed, bedding and building materials (as it is the usual practice in the study area). The similar or higher N and P exported from the low input systems compared to the high input systems at Chuka were due to differences in the crops planted and yields (Tables 2 and 8). Baby corn was planted in the high input systems which had very low nutrient content in the exported products as compared to maize and beans grains in the low input systems. This was further compounded by the higher yields of maize and beans relative to baby corn. On the other hand, the low yields of maize and beans relative to baby corn offset the effect of nutrient content of the different crops at Thika. There are generally positive N, P, and K partial balances under Org-High, indicating that NPK levels are not limiting factors in this system and suggesting that, in the long term, Org-High has the potential to assure soil productivity and sustain crop yields. By contrast the near to zero or negative N and K balances in the high input conventional system and the two low input systems give an indication that these systems continue to deplete nutrient stocks (Table 9). It also implies that nutrient application in low input conventional and organic systems is inadequate. This gives rise to concerns about the sustainability of conventional systems and low input organic system. The results may however change if all the nutrient path ways (as mentioned in Section 2.4) are considered in full nutrient balance calculation. These results are in line with the findings of Surekha and Satishkumar (2014) who, in a 5 year field experiment in India, reported positive and higher N and P partial balances for organic systems than in conventional systems. Onwonga and Freyer (2006) who studied the impact of traditional farming practices (TFP) on nutrient balances in smallholder farming systems in Nakuru District Kenya, reported negative nutrient balances (N, P and K) in all cropping activities with the highest nutrient depletion rates when the land was used for pasture, fodder or cereals. DeJager et al. (2001) also assessed the sustainability of low external input agriculture (LEIA) technologies and conventional farm management at different input levels, and concluded that subsistence-oriented farm management systems resulted in serious N-depletion and that 60-80% of farm income is based upon nutrient mining. It is therefore important to ensure appropriate field management of the harvestable crop biomass in conventional systems and to improve nutrient management in the low input systems to assure the perpetuation of productive agroecosystems and sustain food production.

5. Conclusions

The study shows that organic farming systems can produce yields equal to conventional systems. Maize inter-cropped with beans enhanced productivity in low input organic systems, and gave similar yields to Conv-Low at both sites. Org-High incurred higher production costs every year than Conv-High but the profit was similar in both systems from the third year onwards (without considering the premium price) due to increases in yields. Taken premium price on organic produce into account from the fourth year on the profit from organic high input system exceeded that from the conventional high input system at both sites. There were significant differences in the environmental impact of the two systems. The partial nutrient balances for conventional systems and the low input organic systems were negative whilst that of Org-High was positive. Our findings demonstrate that high input organic farming is productive, economically viable (especially taking premium prices into account) and resource conserving, and can contribute to sustainable agricultural production in Kenya. In order to utilise the full potential of organic farming appropriate policy measures need to be put in place. For example, more attention has to be paid to the use of simple machinery and techniques in reducing production costs in organic farming. It is also important to develop appropriate marketing opportunities for organic produce, and to implement policy measures to ensure that the economic benefits from this premium market actually reach the farmers. In the low input farming systems, intercropping of maize and beans should be given high priority. However, the low and often negative gross margin, benefit cost ratio and the higher N and K export from the low input farming systems is of great concern. It suggests a revisit to the recommended rates of nutrient (especially, N and P) application in small scale farming systems in Kenya. Similarly, the high nutrient export from Conv-High is also of great concern and there is the need to improve management practices to conserve resources.

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Appendix A. Supplementary data

Supplementary data associated with this article can be found, in the online version, at http://dx.doi.org/10.1016/j.agee.2016.10.001.

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