TI 2014-114/V
Tinbergen Institute Discussion Paper

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Wouter Zant*

Abstract

We exploit plot data from the agricultural module of the third Malawi Integrated Household Survey (IHS-3) to investigate how organic cultivation techniques contribute to productivity of non-subsidized local maize and what to expect from using organic inputs on a larger scale. We approximate organic inputs with crop combinations and livestock, and use matching techniques for estimating impacts. Productivity of *local maize–bean*, *local maize–groundnut* and *local maize–nkhwana,* each combined with livestock and chemical fertilizer, is shown to be statistically similar to productivity of fertilized maize mono-cropping. Simulations show that large increases in total maize production are potentially feasible under conversion to organic cultivation techniques. Limited availability of labour and livestock are likely constraints.

JEL code: Q12, O13, O55

Key words: crop productivity, soil fertility, organic inputs, Green Revolution, Malawi, Africa

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Acknowledgements

I would like to thank Rodney Lunduka, Remco Oostendorp, Chris Elbers, Christopher Gilbert, Ken Giller, Kei Otsuka, James Thurlow, participants of the 4th International Conference of African Association of Agricultural Economists, September 22-25, 2013 in Hamamet, Tunisia, participants of the PEGNet Conference "How to Shape Environmentally and Socially Sustainable Economies in the Developing World – Global, Regional, and Local Solutions", October 17-18, 2013 in Copenhagen, Denmark and colleagues of the VU University for helpful comments and suggestions on previous versions of this paper. All remaining errors in the paper are the responsibility of the author.

1. Introduction

Gains in agricultural productivity are essential for poverty alleviation and aggregate economic growth in sub-Saharan Africa (SSA), as convincingly set out by de Janvry and Sadoulet (2010). This claim is substantiated, in the first place, by the relatively large size of agriculture in SSA economies. Additionally, three mechanisms feature as main driving forces of economic activity in nearly all SSA economies: 1. Large multiplier effects from SSA agriculture to the remaining sectors of the economy and, conversely, small multiplier effects from SSA non-agricultural sectors to agriculture; 2. A comparative advantage of SSA agriculture and a comparative disadvantage of non-agricultural sectors – the latter mainly due to a lack of economies of scale – and 3. The relative importance of transmission of productivity growth in food production, into food prices and labour costs, due to incomplete tradability between often isolated regions. De Janvry and Sadoulet further note the consensus and recognition from 2000 onwards among multi-lateral development agencies and SSA governments on the key role of agriculture, following decades of neglect of agriculture. Several other studies reach similar conclusions (see contributions in the same supplement of the Journal of African Economies, Valdés and Foster (2010), Diao et al. (2010), Block (2010), Nin-Pratt et al.(2009) and Christiaensen et al. (2011)).

Given the consensus on the key role of productivity growth in agriculture for poverty alleviation and aggregate economic growth, determinants of productivity growth in agriculture become the focus of interest. Research on productivity in crop production in developing countries has particularly gained momentum since the Asian Green Revolution. Mechanisms underlying the success of the Asian Green Revolution have been investigated in several studies. Productivity in crop production in Asia is shown to be achieved by a well balanced combination of fertilizer inputs, fertilizer responsive high yielding rice and wheat varieties, and supporting

agricultural research (Otsuka and Kalirajan (2006), Hazell (2009)). However, agriculture in Asia and Africa differ in many respects: amongst other things, SSA prices of chemical fertilizer tend to be relatively high. High costs of chemical fertilizer and related unfavourable output-fertilizer price ratios have shifted attention towards local alternatives, notably organic fertilizers such as the use of manure from cattle, residues from crops and other benefits from mixed cropping systems. The objective of this paper is to investigate the contribution of organic inputs to crop production and productivity, jointly with and without chemical fertilizer[1] on the basis of household survey data.

The paper is organized as follows. In Section 2 we review the literature in this field focusing on the mechanisms behind the Asian Green Revolution and on agronomic research on the benefits of organic inputs in agriculture. In Section 3 we present descriptive statistics on productivity in maize cultivation in Malawi, compare aggregate with household data and summarize policies in the Malawi economy to enhance productivity in maize cultivation. In Section 4 we propose a methodology to estimate the contribution of organic inputs to productivity. In Section 5 we present estimations of productivity under organic techniques using plot data of Malawi household surveys. In Section 6, we simulate the potential growth if organic techniques are used on a larger scale and we elaborate on possible constraints to achieve this growth. We conclude with a summary and conclusion in Section 7.

[1] In this paper we make a distinction between chemical fertilizer and organic fertilizer and inputs. The former stands for processed chemical agro-minerals and manufactured fertilizer, the bulk of which is urea and various combinations of nitrogen, phosphorus and potassium (mostly referred to as NPK, and, for example, sold in the Malawi market as 23:21:0 4S), the latter stands for the use of crop residues, animal manures and composts, crop rotation, intercropping and other organic technologies and inputs. Chemical fertilizers need to be purchased in the market and organic fertilizer and inputs are available at the farm as by-products of other production.

2. Productivity growth in sub-Saharan Africa agriculture

What about the green revolution for Africa?

How does growth of crop productivity come about? Recent research on the causes and backgrounds of the Green Revolution in Asia and its potential lessons for Africa are useful in this context (Otsuka and Kalirajan, 2006; Otsuka and Yamano, 2005; Djurfeldt et al., 2005; Hazell, 2009; Otsuka and Kijima, 2010; Larson et al., 2010 and references in these articles). The initial growth in crop productivity in Asia – notably growth in productivity of rice and wheat cultivation – was achieved by the introduction of modern fertilizer responsive high yielding varieties, replacing traditional, varieties. Introduction of these high yielding varieties primarily took place in favourable irrigated areas. Subsequently, sustained yield growth was achieved by continuous improvement and dissemination of new varieties. In most cases these new varieties concerned variants of existing varieties which were adjusted to local conditions by national agricultural research institutes. Easy reproducibility of seeds by farmers further facilitated widespread distribution and adoption. Easy reproducibility has quickly and effectively transformed these technological improvements into a public good[2]. The application of fertilizer combined with the use of fertilizer responsive varieties and adequate efforts of international and national agricultural research institutes to improve these varieties were the key drivers of the success of the Asian Green Revolution. The role of an enabling and supportive economic, marketing and policy environment was important in introducing and sustaining momentum in agricultural productivity growth (Hazell, 2009; Dorward et al., 2004).

[2] Hybrid maize in Africa suffers from large drops in productivity if recycled by farmers. This stands in the way of disseminating the hybrid maize technology and converting the technology to a public good. This "drop in productivity if recycled" also enhances monopoly power for the Government (if hybrid seed is subsidized) or for the seed companies (if hybrid seed is supplied by the market).

Changes in Asian rice and wheat cultivation were also accompanied by low chemical fertilizer prices relative to rice and wheat output prices, and this establishes another key issue. If chemical fertilizer prices are high and output prices are low, it is rational for farmers not to use chemical fertilizer. In other words, high prices of chemical fertilizers, but also a lack of complementary inputs such as irrigation and extension infrastructure, discourage farmers from exploiting the potential benefits from green revolution technology. Chemical fertilizer prices in Africa tend to be high due to a high dependence on chemical fertilizer imports and due to a poor road infrastructure and thereby high transaction costs. Use of chemical fertilizer is adversely affected by these high costs. Although the larger part of African farmers may purchase some chemical fertilizer, quantities purchased are practically always well below recommended per hectare quantities (e.g. Vanlauwe and Giller, 2006). In several sub-Saharan countries ratios of output value relative to fertilizer cost may nevertheless be favourable (Vanlauwe and Giller, 2006).

A strategy to avoid high prices of imported chemical fertilizer is to further develop the potential of organic fertilizers. This is also proposed in a few Asian Green Revolution studies: *"One approach is to use manure from cattle and leaves from agro forestry trees, which possess nitrogen fixation capacity."* (Otsuka and Kalirajan, 2006), and *"A new farming system based on manure produced by improved dairy cows in the highlands of Kenya is promising because the data suggest a potential to nearly double maize yields"* (Otsuka and Yamano, 2005). It is further noted that *"…while the Asian Green Revolution can be termed seed-chemical fertilizer revolution, the African Green Revolution might be based upon new farming systems consisting of seed-livestock-agroforestry interactions"* (Otsuka and Kalirajan, 2006). Djurfeldt et al. (2005)

find that a combination of organic inputs and chemical fertilizer is needed for sustainable yield growth in African agriculture, using a micro data set for eight African countries.

Soil fertility and organic techniques

This shifts attention to soil fertility and soil fertility management. Vanlauwe et al. (2010) define Integrated Soil Fertility Management (ISFM) as: *"a set of management practices that necessarily include the use of fertilizer, organic inputs and improved germplasm, combined with the knowledge of how to adapt these practices to local conditions, aimed at maximizing agronomic use efficiency of the applied nutrients and improving productivity. All inputs need to be managed following sound agronomic principles."* Vanlauwe et al. (2010) emphasize the wide diversity of farming systems and environments that influence effectiveness of any fertilizer, pointing at soil properties (nutrient balance, water retention, depth of soil, slope and positioning), farmer wealth (both financial and human), climate (rainfall, both quantity and timing, humidity, temperature) and structure levels (governance, policy, infrastructure and security levels).

Conclusions of impact assessments of organic agricultural production systems like crop rotation, intercropping, mixed cropping and multiple cropping, usually taking (continuous, unfertilized) mono-cropping as counterfactual (see e.g. Waddington, 2003; Barrett et al., 2002a and several other contributions in these books) are difficult to generalize[3]. However, there appears to be consensus that continuous mono-culture needs to be avoided: for a variety of reasons – most prominently incidence of diseases and pests, and biased use of soil nutrients leading to soil depletion – continuous mono-culture will eventually always lead to lower crop yields (see e.g. Sauer and Tchale, 2009). With regard to soil fertility management it is generally

[3] In discussing the literature we have made an arbitrary selection of a vast body of research. This literature is not only vast, but many issues are disputed, not well understood or not researched yet. Many agronomists, agricultural economists and ecologists may feel uncomfortable with the choices made in this paper. However, the fundamental biochemical and agronomic mechanisms at work in crop cultivation are not the key subject of this paper.

accepted that productivity potential is optimized with a combined application of organic and chemical fertilizers, within the constraints of social and economic viability, and making a maximum use of locally available resources (Vanlauwe et al., 2001; Vanlauwe and Giller, 2006; Vanlauwe et al., 2010). Empirical estimates of the contribution of organic fertilizer to crop production together with knowledge on the degree of substitutability between different inputs are useful to assess scope and potential contribution of organic fertilizers in future productivity growth of sub-Saharan Africa. Place et al (2003), who investigate the potential of combined use of organic inputs and chemical fertilizer in smallholder African agriculture, observe a growing use of integrated soil fertility management techniques. Most often observed practices are: animal manure, compost, crop residues, natural or improved fallow, intercropping or relay systems[4], crops combined with legumes and biomass transfer. In many cases use of organic inputs is better established than use of chemical fertilizer. Apart from a source of nitrogen, organic inputs offer other nutrients, increase in organic matter, reduction of diseases and pests and improvement of soil moisture (see e.g. Rusinamhodzi et al., 2012).

Snapp (1998) aims at characterizing the general soil nutrient status in Malawi, revealing the relationship between organic C and other soil characteristics and describing these characteristics, all for smallholder farming in Malawi. Organic technologies such as mulching and incorporation of organic materials are suggested as potential alternatives to improve acidity of soils and enhance their nutrient status. In view of insufficient availability of organic resources, intercropping with legumes is suggested: such intercropping will increase high quality organic residues and N for biological nitrogen fixation and enhance crop productivity and nutrients status (see also Rusinamhodzi et al., 2012 for a similar study on Mazambique).

[4] Also and more widely referred to as spatial crop diversification (intercropping), as opposed to intertemporal crop diversification (crop rotation).

A small number of studies record positive interactions between organic and mineral inputs (urea + crop residues; ammonium nitrate + manure). Evidence further suggests that mineral inputs alone are much less effective and better applied in combination with organic inputs. There is some limited evidence on profitability of some of these techniques. Underlying mechanisms, however, are not always understood. Nitrogen fixing impacts of the use of crop residues, however, are reasonably well documented opposed to impacts in the area of avoiding diseases and improving soil structure. Crop residues, particularly residues from legume crops and leaves from agro-forestry trees, have a beneficial effect on soil fertility due to nitrogen fixing. *"Yields of cereal crops are generally better in legume-cereal rotations than where cereals are cultivated year after year, and this effect is often seen even when legumes with a high N-harvest index is grown"* (Vanlauwe and Giller, 2006). They argue that the contribution to soil fertility depends on the amount of N_2 fixed in relation to the amount removed from the system in the crop harvest and these characteristics vary across crops. Snapp et al. (1998) investigate on a trial basis the potential of maize and maize/bean intercropping, both fertilized and not fertilized, and show net benefits of fertilized maize/bean intercrop to be two fold higher than fertilizing maize alone. They concluded that this is an attractive strategy for low input subsistence farming. Groundnuts and cowpeas are also identified to have a particularly positive nitrogen fixing capacity (see e.g. Rusinamhodzi et al., 2012). The use of groundnut for crop rotation with maize, next to a number of other intercrops are recommended through the Soil Fert Net network (Mecuria and Waddington, 2002). Other sources recommend pigeon peas as rotation crop (Chamango, 2001; Snapp et al., 2002). Evidence is not restricted to African agriculture: Berzsenyi et al. (2000) report on a long term (40 years!) crop rotation experiment in Hungary, with maize and wheat, seven crop sequences and five fertilization treatments, and conclude that in both wheat and maize

monoculture yields are lower than in crop rotations, the yield increasing effect is largest the larger the number of rotation crops, and the difference in maize yield due to crop rotations should be attributed to nitrogen supplies.

Some authors claim that cassava cultivation also improves soil fertility: *"Farmers in Ghana, Benin and Kenya all report that cassava has a similar effect on improving soil fertility compared with continuous maize cultivation, presumably as cassava extracts less nutrients and returns more litter to the soil than continuous maize!"* (Vanlauwe and Giller, 2006). However, it is an open question whether cassava residues are a source of organic fertilizer: cassava residues provide only recycled nitrogen as the crop does not fix nitrogen. The harvest of large cassava root tubers is sometimes claimed to be disruptive and associated with soil degradation and not with enhanced soil fertility (see Fermont et. al., 2010, for an assessment of popular beliefs on cassava cultivation). Diversification in crop cultivation through intercropping, mixed cropping, relay cropping or crop rotation is also claimed to have beneficial impacts in terms of environmental sustainability, soil improvement and crop productivity, mainly through suppressing outbreaks of pests and diseases, dampening pathogen transmission and, thereby, increasing resilience (see e.g. Lin, 2011; Snapp et al. 2010).

The objective of this study is to investigate if, to what extent and for which crop-fertilizer combinations, plot level evidence from a representative household survey supports a beneficial impact of organic inputs in staple food production in subsistence agriculture in Africa. Malawi, a landlocked economy, dominated by agriculture, characterised by subsistence farming and with a high incidence of poverty, forms the case study. We extract plot data from the agricultural

sections of the Third Integrated Household Survey of Malawi (IHS-3[5]). Apart from household and community information, this survey offers agricultural production information at the plot level[6].

3. What do the data tell about productivity in maize cultivation?

Production per hectare over time and between regions: aggregate data

Before we proceed with the empirical investigations we discuss some facts and figures of maize cultivation in Malawi, compare aggregate with household data and summarize the major policies In Malawi aiming at productivity growth in maize cultivation. Maize is the key staple crop in Malawi, both from the perspective of consumption of households and from the perspective of agricultural production. Maize constitutes the most import single food item in the Malawi diet: well above 50% of the total per capita calorie intake is accounted for by maize. Maize is also cultivated by nearly all rural households (close to 100%), mainly on subsistence grounds. Under these conditions productivity and productivity growth in maize cultivation is a key determinant to increase welfare and economic growth and to alleviate poverty. What is the level of productivity in maize cultivation?

[5] The data from the third Integrated Household Surveys of Malawi (IHS-3) are downloaded from the World Bank LSMS website. Occasional assistance from the Poverty Team of the Development Research Group of the World Bank in using the data is kindly acknowledged.

[6] In IHS questionnaires a plot is defined as follows: A plot is a continuous piece of land on which a unique crop or mixture of crops is grown, under a uniform consistent crop management system. It must be continuous and should not be split by a path of more than one metre in width. Plot boundaries are defined according to the crops grown and the operator (Third Integrated Household Survey, Agriculture Questionnaire). This definition comes very close to the agronomic definition of a plot. Nevertheless, identical plots according to a household survey may still be different from identical plots according to an agronomic field experiment, because much more conditions are controlled in the latter.

Table 1 Production per hectare: aggregate data

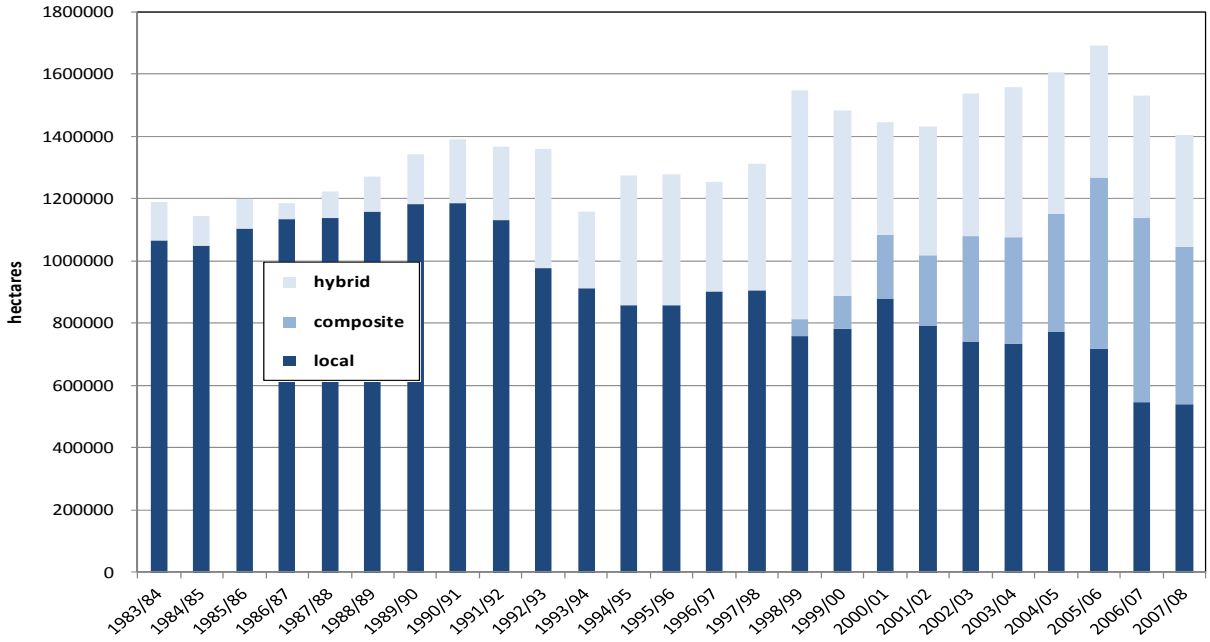
	local maize			hybrid maize		
	North	**Central**	**South**	**North**	**Central**	**South**
1983/84 – 1987/88	879	1160	873	3188	2920	2222
1988/89 – 1992/93	730	967	660	2896	2709	2208
1993/94 – 1997/98	897	884	651	1824	2171	1817
1998/99 – 2002/03	929	922	682	2226	1977	2207
2003/04 – 2007/08	922	855	699	2410	2201	1998

Source: Ministry of Agriculture and Food Security, Agro-Economic Survey
Note to table: Original data are by crop year and district or rural development program (RDP). The presented figures in the table are weighted 5 year averages in kilograms per hectare.

We first consider the available aggregate data at the district level, for the period from 1983 to 2008, publicly available from the Ministry of Agriculture and Food Security[7]. Considering all regions, maize production per hectare by variety, shown in Table 1, indicates a nearly threefold fifference between the lowest (local maize) production per hectare (averages between 650-1160kg/ha) and the highest (hybrid maize) production per hectare (averages between 1820-3200kg/ha). In general, yield levels in the south are lower, both for local and hybrid maize. Variability of production per hectare (not shown) is larger for hybrid maize than for local maize[8]. Over the long run[9], from 1983/84 to 2007/08, production per hectare showed little improvement for local maize but decreased for hybrid maize until the turn of the century where after it stabilized at around 2000 kg per hectare.

[7] It is sometimes claimed that these data cannot be trusted, specifically because MoAFS has an interest to present data that reflect positively on seed and fertilizer policy. This has direct implications for the decisions made in this study (see following sections). However, for the moment we ignore this.
[8] Suri (2011) finds a smaller spread of the frequency distribution of (the log of) hybrid relative to non-hybrid maize, based on household data for Kenya.
[9] Since maize in Malawi is a rain fed crop, short run fluctuations in production per hectare, caused by drought, are large. In the past (1991/92, 1993/94 and 2004/05) droughts have reduced production per hectare to around 460 kg for local maize and 1070 for hybrid maize. On the basis of research under experimental conditions Smale (1995) reports decreases in yield due to drought of 600 to 900 kg for local varieties, and 800 to 1800kg for hybrid varieties.

Figure 1 Maize Crop Area by variety



Source: Ministry of Agriculture and Food Security, Agro-Economic Survey

The attractive high yield of fertilized hybrid maize has triggered a lively debate on the impact of the (successful) Malawi hybrid maize seed and fertilizer subsidy schemes (see e.g. Ricker-Gilbert and Jayne, 2008; Dorward and Chirwa, 2011; Chibwana et al. 2012; Mason and Ricker-Gilbert, 2013; Arndt et al., 2013) and on technology choice in subsistence agriculture in general, against the background of the widespread limited take-up of high productivity technologies in SSA agriculture if not heavily subsidized (see e.g. Just and Zilberman, 1983, 1988; Kim et al 1992; Suri, 2011, and some recent experimental studies[10]: Duflo et al., 2008, 2011; Beaman et al., 2013). Nearly without exception these studies investigate high yielding hybrid maize, the

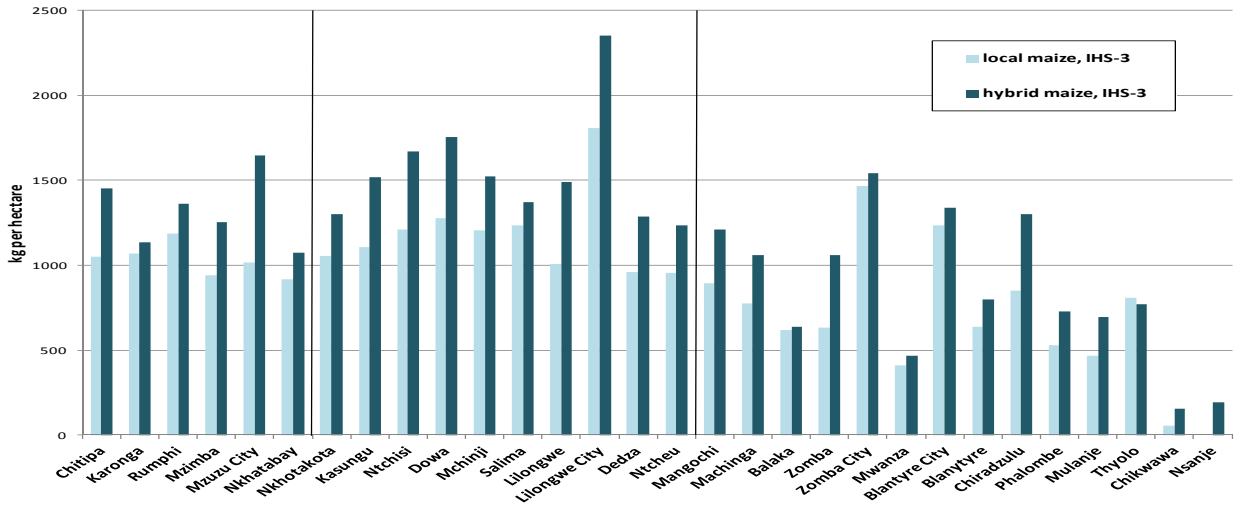
[10] Various explanations have been put forward for the limited success of the high yielding hybrid maize and the persistence of low yielding maize varieties. Duflo et al. (2008) explain the low use of chemical fertilizer with present biased time preference, Suri (2011) points at heterogeneity in costs and returns, Udry and Conly (2010) emphasize the phenomenon of social learning in the adoption and diffusion of technologies and Beaman et al. 2013 find that re-optimization of complementary inputs blurs identification of fertilizer on productivity and they also find no impact of fertilizer use on profits.

high-end technology choice. For reasons to be elaborated below it is decided in this study to take a drastically different route by focussing exclusively on local maize, the low cost bottom-line technology choice. Our work complements an area of research suggested in the 2008 World Development Report and a number of related papers that highlight the tremendous gain that may be achieved if African farmers would convert to best practise agriculture (see Sarris et al., 2006; Christiaensen and Demery, 2007; World Bank, 2007 (WDR2008); Christiaensen, 2009; Christiaensen et al. 2011).

Data used for empirical estimation: plot level survey data

The empirical work in this study is based on plot-level data from the agricultural section of the Third Integrated Household Survey (IHS-3), a representative household survey of Malawi. In general the use of plot information reported by households creates a large number of observations, which offers good opportunities for analysis: the number of local maize plots identified in IHS3 is 6,551.

Figure 2 Production per hectare of local and hybrid maize by district



Source: Integrated Household Survey 3

For comparison with the aggregate data in Table 1 we have summarized production per hectare by district according to IHS-3 in Figure 2, both for local maize and for hybrid maize: the vertical lines in the figure identify, from left to right, the districts in the north, central and south. The difference between Table 1 and Figure 2 is spectacular: the level of hybrid maize production per hectare is dramatically lower according to IHS-3 (450 to 1100 kg/ha lower), while local maize production per hectare is more or less similar according to both sources. Consequently, the difference in production per hectare of hybrid and local maize in the IHS-3 data is seldom as large as suggested in the aggregate data[11]: on the contrary, in some districts local maize production per hectare is similar or even larger than hybrid maize. In fact, the moderate difference between hybrid and local maize may go a long way in explaining the limited adoption of hybrid maize, the high-end technology in maize cultivation. It also suggests that local maize, the low-end technology is not that backward. Regional variation in production per hectare as apparent from the aggregate data is also observed in the plot data with the lowest production per hectare realised in the south. Finally, the figure appears to support higher levels of production per hectare for those districts that are near to urban areas (Lilongwe, Blantyre, Zomba and Mzuzu). Next, we argue why it makes sense to concentrate the empirical work on local maize.

Sustainability of local maize versus hybrid maize

The high cost of fertilizer and the search for cheaper alternatives in the form of organic inputs is the primary justification to study the determinants of local maize yields, rather than hybrid maize yields. In the empirical work we will compare local maize yields under mono-cropping with these yields under a variety of combinations of mixed cropping, animal manure and chemical

[11] The observation of the extremely high hybrid maize production per hectare according to MoAFS supports the suspicion that these data are possibly not correct.

fertilizer inputs. The reasons to focus exclusively on productivity of local maize, rather than hybrid (or composite maize[12]) are:

1. The share of local maize in total area cultivated with maize, is persistently large (see Figure 1) despite a large yield differences between local maize and hybrid maize in aggregate data (see Table 1)[13]. At the same time, in household data – which we tend to give a larger weight – the difference in production per hectare of local and hybrid maize is moderate (see Table 2, and Figure 2). Both considerations make local maize an attractive candidate to consider in efforts to increase productivity in maize cultivation.
2. In contrast with hybrid maize cultivation, local maize cultivation has moderate input requirements, and, hence, (relatively) low input costs. Purchased seeds and chemical fertilizer are less critical and less applied. Hence, a distribution network for these inputs is less essential. Technology dissemination also does not depend on such a network. Hybrid maize cultivation, on the other hand, requires a well-developed distribution network for seeds and fertilizer that is capable of delivering these inputs timely, together with related crop advice. Technology dissemination rolls out through the input distribution network. In many African countries and specifically in Malawi this is the responsibility of the government which heavily subsidizes hybrid seed and fertilizer. The fiscal sustainability of this arrangement for hybrid maize cultivation remains an open

[12] How does composite maize fit in this study? Average productivity in composite maize is substantially higher compared to local maize. Simultaneously, composite maize does not suffer from poor recycling properties, does not face high input cost and is also not, or at least very much less, subsidised. For these reasons some authors consider composite maize (also open pollinated varieties (OPV)) to be a promising alternative (see e.g. Pixley, K. and M. Bänziger, 2001). Composite maize could be seen as a special type of local maize and composite maize data could be analyzed jointly with the local maize data. However, on the grounds of disturbing homogeneity of the data, we have decided not to include the composite maize data. There is also a data availability issue: the number of recorded plots with composite maize cultivation in the IHS-3 data is (very) small.

[13] In the literature we find various explanations for this choice of farmers: high transaction costs (Key et al., 2000; De Janvry et al., 1991), lack of profitability (e.g. Suri, 2011) and consumer preferences (e.g. Smale, 1995; Lunduka et al., 2012).

question (see e.g. Dorward and Chirwa, 2011; Mason and Ricker-Gilbert, 2013)[14]. Politicians may also exploit these schemes as instruments for electoral objectives rather than to seek an effective use of resources in terms of welfare. Finally, the exit strategy of subsidy schemes is seldom specified.

3. If seed and chemical fertilizer distribution is taken up by the private sector, it is unclear if smallholder farmers will benefit from a – possibly – fragmented and uncompetitive seed and fertilizer industry. Dependence on a monopolistic seed and fertilizer industry is an unattractive prospect for generally weak smallholder farmers: it is unlikely that an uncompetitive seed and fertilizer industry will solve the problem of high (transaction) costs of seed and fertilizer for smallholder farmers.
4. On-farm seed propagation of local maize is common and widely practised. This makes local maize cultivation sustainable from an agricultural perspective. On the other hand, on-farm recycling of cultivated hybrid maize is possible but at the cost of large reductions in yield which makes agricultural sustainability of hybrid maize low[15]. Also the diffusion of high yielding varieties, and hence the dissemination of new technologies, is drastically hampered by this property and made dependent on the seed and fertilizer distribution network. The monopoly power of the seed and fertilizer distribution network is strengthened by this property.

[14] Additionally, and related to the commitment of the Malawi Government to the various hybrid maize fertilizer and seed subsidy programs, it is sometimes claimed that statistical data on (hybrid) maize production and productivity are not correct. This appears to apply particularly to (aggregate) data distributed by the Ministry of Agriculture and Food Security. Mason and Ricker-Gilbert (2013) find evidence that input subsidy programs may be politically motivated. Whatever is the case, we avoid any suspicion of using data manipulated for these purposes by focusing on local maize.

[15] With the limited possibilities for on-farm recycling of hybrid maize, it will be difficult to convert this technological progress into a public good. This is in sharp contrast with the development of high yielding rice varieties in Asia, during the Green Revolution.

5. Local maize is a much less prominent concern of economic policy than hybrid maize. As a result it is less likely that local maize data are tampered with. In this context we note that the IHS data on local maize roughly correspond with the MoAFS aggregate data[16], but this claim is hard to maintain in the case of hybrid maize. Investigations based on local maize data are therefore likely to generate higher quality recommendations than those based on hybrid maize data.

Determinants of maize productivity from IHS data

Table 2 summarizes mean and standard deviations of a number of key variables, and includes a comparison between hybrid and local maize. The number of households in the IHS-3 is 12,271. Household size is 4.6 household members (mean). Farm households are around 80-85% of all households and average cultivated area by farm household is 0.74 ha. Production per hectare of local maize is 806kg (median), around 73% of hybrid maize production per hectare (median). Use of chemical fertilizer increases for local maize increases over the years and is at 70% and for hybrid maize at 82%. The assumption of zero use of chemical fertilizer in local maize cultivation (see Suri, 2011) is clearly not supported by the Malawi data. The increased use of chemical fertilizer over the years likely reflects the expansion of fertilizer subsidies. Livestock breeding is similar between local maize and hybrid: an average of 33% of households rears livestock. Finally hired labour is low for both local maize and hybrid maize, slightly higher for hybrid maize, and incidence averages vary between 22 and 28%.

[16] Productivity in local maize over the years (using IHS-1, 2 and 3) is also more or less in line with the aggregate data from the previous section. The mean (median) local maize productivity in kg per hectare is around 720 (495) in IHS-1, 745 (575) in IHS-2 (2003-04) and 1143 (786) in IHS-3 (2009-10).

Table 2 Integrated Household Survey Data (IHS-3): descriptive statistics

	observations	mean	standard deviation
No. of communities	768		
household size (#)	12271	4.597	2.220
household acreage (ha)	10118	0.740	0.655
plot size (ha)	18916	0.397	0.383
maize plots (ha)	12472[2]	0.422	0.403
local (ha)	6551	0.443	0.433
hybrid (ha)	6071	0.401	0.368
yield (kg/ha)[1]			
local (kg/ha)	6534	805.8	
hybrid (kg/ha)	6006	1099.1	
fertilizer (dummy)			
Local	6139	0.701	0.458
hybrid	5631	0.822	0.382
mono crop (dummy)			
local	6139	0.490	0.500
hybrid	5631	0.576	0.494
livestock (dummy)			
local	6139	0.329	0.470
hybrid	5631	0.334	0.472
hired labour (dummy)			
local	6136	0.218	0.413
hybrid	5621	0.276	0.447

Notes to Table: 1) since the yield distribution is skewed towards the high-end we show median values instead of mean values; 2) crops cultivated on a single plot are recorded to a maximum of five different crops for each plot and this explains why the sum of local and hybrid maize plots is larger than the number of maize plots.

4. How to identify the contribution of organic inputs to production per hectare?

Organic inputs in agricultural production: a simple framework

The question arises what are the determinants of local maize productivity? How does the contribution to productivity vary over these determinants? What is the impact of fertilizer and organic inputs on productivity? Is it possible to identify combinations of fertilizer use and organic inputs generating (relatively) high productivity levels? In order to investigate how organic inputs contribute to productivity we consider the following relationship[17]:

$$y_{hi} = \beta_0 + \sum_j \beta_j x_{ji} + \sum_k \beta_k z_{ki} + \omega_h \qquad (1)$$

[17] The proposed relationship is compatible with various specifications of a (household) production function (see for example Suri, 2011). Since the derivation of the empirical specification from profit maximizing household behavior is not central to this paper it is decided to omit such a formal derivation.

$where$

y_{hi} $is\ production\ per\ hectare\ on\ plot\ i\ of\ household\ h,$ x_{ji} and z_{ki} $are\ resp.\ j\ and\ k$ $exogenous\ and\ endogenous\ explanatory\ variables\ for\ plot\ i\ and\ \omega_h\ are\ household$ $fixed\ effects$

We are specifically interested in the impact of chemical fertilizer and organic inputs on productivity. We use the expression organic inputs as a generic concept for cultivation practices that, in some way or another, exploit other crops, crop wastes or other crop cultivations, or that make use of manure from cattle. Organic inputs are inputs which are (often) available at the farm at low cost, opposed to chemical fertilizers that have to be purchased on the market. Agronomic research further supports (see literature review) an array of additional beneficial impacts on soil characteristics, and this also contrasts with the impact of chemical fertilizer. For the purpose of our methodological framework two stylized types of organic inputs are identified, namely combinations of different crop cultivations on one plot and the number of livestock in the household. Together with the use of chemical fertilizer we have three inputs of key interest. We rewrite equation (1) as follows:

$$y_{hi} = \beta_0 + \sum_m \beta_{1,m}\ crop\ comb_{mi} + \beta_2\ fert_i + \beta_3\ lvstk_i + \sum_j \beta_j x_{ji} + \sum_k \beta_k z'_{ki} + \omega_h \qquad (2)$$

$where\ \ crop\ comb_{mi}\ is\ crop\ combination\ m, fert_i\ is\ fertilzer\ use, and\ lvstk_i\ is\ livestock,$ $all\ on\ plot\ i$

The coefficients of interest are $\beta_{1,m}$, β_2, and β_3: these coefficients reflect how the use of these inputs impacts on local maize productivity.

Synergies by combinations of inputs

The literature suggests that synergy between inputs is likely to play a key role in productivity of crop cultivation (see literature review). Inputs in agriculture are not used in isolation but

integrated with other inputs and together form a balanced and well-chosen package of inputs that aims to achieve the highest possible productivity in a given situation. The current specification of the production function (see equation 2) does not reveal these synergies. If impacts are disentangled by interacting inputs, we are able to identify and quantify these synergies and assess their relative contribution to productivity. Since full interaction of all inputs is not useful (large number of coefficients, interpretation complicated), we propose a model with only those interactions, that are key to our investigations. Hence, we interact crop combinations[18], with livestock and chemical fertilizer. Formally this is specified as follows:

$$y_i = \beta_0 + \sum_j \beta_j \; I\,[crop\ comb_{pi} * fert_{qi} * lvstk_{ri}] + \sum_n \beta_n x_n + \sum_k \beta_k z'_k + \omega_h \qquad (3)$$

$$where \;\; I[..]\ is\ the\ interaction\ operator\ and\ j = p\ x\ q\ x\ r$$

Bias in estimation due to endogeneity

Ordinary estimations of the productivity relationship formalized in equation (3) are likely to be contaminated with severe endogeneity and will generate biased coefficients[19]. Variables will be endogenous if they represent the outcomes of discretionary decisions controlled by the household at the start of the season. For example, households will decide to use fertilizers on soils which are most suited to their use. This makes crop combinations, fertilizer use, manure – variables of key interest to this study – but also use of labour, both household and hired, and other inputs endogenous. Conversely, other variables like properties of the plot (size, soil type, slope),

[18] It should be noted that mono cropping is one of these "crop combinations".
[19] A naïve production function specified in equation (3) is nevertheless estimated and presented in the appendix for reference.

household characteristics (age, gender and education of household head) and travel time and distance to other locations may safely be assumed to be exogenous.

With non-experimental data causal inference or identification of treatment effects may be achieved, amongst others, by matching or related techniques (see Nicols, 2007). These techniques are all concerned with creating proper counterfactuals for observed data, either by weighing or by estimation, and subsequently compare observed outcomes with constructed counterfactuals. The techniques simultaneously overcome the endogeneity problem: they offer asymptotically unbiased and consistent estimates of treatment effects (see e.g. Morgan and Harding, 2006).

Most applications of matching and related techniques require the treatment variable to be binary. In our investigations this implies that interactions of crop combination, chemical fertilizer use and number of livestock are converted to binaries. Since such a conversion aggregates a large variety of intensities of input use, it clearly introduces additional measurement error and precludes the accurate estimation of marginal productivity of inputs. Further, covariates used to match untreated observations with treated observations are exogenous and not affected by the treatment, following requirements to apply matching technique (see Imbens, 2004). In terms of our methodological framework, the outcome model is now specified as:

$$y_i = \beta_0 + \sum_j \beta_j \; I\,[crop\ comb_{pi} * fert_{qi} * lvstk_{ri}] + \sum_n \beta_n x_n \qquad (4)$$

Matching and related techniques used for the estimations in this paper are further elaborated in the estimation section. Apart from a model of the outcome variable, some of these techniques also model the treatment variable. We proceed likewise and propose the following treatment model:

$$I[crop\ comb_{pi} * fert_{qi} * lvstk_{ri}] = \gamma_0 + \sum_m \gamma_m x_m \quad (5)$$

Empirical specification of variables: approximations and measurement error

The explanatory variables used in estimations are at plot level i, x_j and z_k (see equation (3) to (5)) contain plot level, household level, community level, district level and survey variables. At the plot level we distinguish plot size (-), distance from plot to home (-), soil type of plot (+/-), inclination of plot (-), crop combinations (+/-), and inputs of labour (+), fertilizer (+), seed (+) and manure (+); at household level: characteristics of the household head (gender (+/-), age (+/-) and education(+/-)), access to labour (+), access to information (+) and access to credit (+); at the community level: distance to markets (-), distance to tarmac road (-) and community size (+); and at the survey level: crop year (+/-), all with the expected sign of the marginal effect of the variable in brackets behind after the variable. Conceptual issues and construction of variables are discussed in Appendix A.

In terms of crop combinations we focus on local maize cultivation combined with, respectively, groundnuts, sorghum, beans, pigeon peas and nkhwana (a local vegetable), apart from – of course – local maize mono culture. These crop combinations have the highest prevalence in the Malawi context, and also contain the combinations that are frequently studied for their agronomic impact (see literature review). Some of the potentially interesting crop combinations on grounds of soil fertility, like *local maize – soybean* and *local maize – cow peas*, are ignored because the number of recorded plots with these crop combinations is relatively small. In the estimations the omitted category in terms of crop combinations is, consequently, a set of miscellaneous crop combinations with a low incidence each.

With respect to crop combinations several issues are unclear. We do not know the exact agricultural system that is employed. What is the intensity of intercropping? Are crops cultivated jointly (mixed cropping, intercropping) or sequentially (crop rotation)? And does this make a difference? We also lack information on the dynamics in cropping systems over the years: are the plots with monoculture maize continuously mono-cropped year after year? Or is there some rotation of crops over the years and in with which crops? And what is the crop sequencing and frequency in crop rotation? Are plots left fallow? Are crop residues in fact used as organic inputs for maize cultivation? In what way are these crop residues used? In summary we do not know exactly, if and in what way intercropping, mixed cropping, relay cropping or crop rotation takes place and if, in what way and to what extent crop residues are used to improve the soil. Hence, there remains an important speculative element in the use of these crop combination variables as approximations for the use of organic techniques (and this also applies to what we identify as mono cropping)[20].

The use of fertilizer is a plot specific binary indicator variable, that make use of answers to the question "Did you use any inorganic fertilizer on this plot during the reference rainy season?" and has a value of 1 if the answer is yes and 0 if the answer is no. Again, we do not know the exact quantity, type, timing, and intensity of fertilizer[21]. We also do not know the application technique, the weather and rainfall conditions, and the nutrient balance of the soil at the time of application. Hence, there will be considerable measurement error in the fertilizer use data.

[20] At the same time agronomic research is also not always clear – and in fact often rather agnostic – about the mechanisms underlying the beneficial impact of organic inputs (see literature review).

[21] In fact, (limited) information on quantity and type of fertilizer is available but we prefer to use a binary indicator variable to avoid issues of matching different types and quantities and related measurement errors.

Finally, the number of livestock is included in the estimations, household variable and not a plot variable. Conceptually, the number of livestock only concerns larger animals (cattle, calves, bulls, donkey, horse, goat, sheep, pigs). Livestock is included with the implicit assumption that dung from livestock – which is assumed to be proportional to the number of livestock – is used to improve soil fertility, and thereby productivity of crop cultivation. Also, and similar to the crop combination variables, we do not know a number of details of the potential use of cow dung (e.g. quantity, type, preparation of dung, timing and intensity of use, application technique, weather and rainfall conditions, nutrient balance of the soil): we simply assume that cow dung is used in crop cultivation and that it is used in a homogenous way.

In summary, we do not know exactly if, in what way and to what extent organic technologies and inputs are used in crop cultivation. We simply assume that crop combinations, livestock and fertilizer variables are proper approximations for respectively organic inputs and chemical fertilizer.

5. Estimation methods, estimations, tests and discussion

Estimation methods and results

We apply a series of techniques to estimate treatment effects with non-experimental data, notably regression adjustment (ra), inverse probability weighting (ipw), inverse probability weighted regression adjustment (ipwra), augmented inverse probability weighting (aipw), nearest neighbour matching (nn) and propensity score matching (ps)[22] (see Nicols, 2007 for causal inference with non experimental data).

[22] In fact, we simply follow the available estimation techniques offered under the teffects command in STATA.

We briefly highlight the intuition of the estimation methods. The impact estimation methods either model the impact variable (ra), the treatment (ipw), both the impact variable and the treatment (ipwra and aipw), compare observations that are similar (nn), and use the estimated probability of treatment or propensity score (ps). Under de regression adjustment method (ra) the outcome variable is regressed on a number of covariates for the treatment observations and for the control observation. Regression outcomes are used to predict potential outcomes (counterfactuals) and these predictions are used to estimate the population average of the treatment effect.

Inverse probability weighing (ipw) fits a model on the probability of treatment using whatever characteristic that is available for all observations. This model is used to construct weights. For the (non)treated the weight is equal to the reciprocal of the predicted probability of (not receiving) treatment, where the probability of not receiving treatment is simply one minus the probability of treatment. Predicted probabilities close to zero or one make this technique unstable (and this corresponds to the requirement that every subject in the sample needs to have a non zero probability to be treated).

The outcome modeling strategy of ra and the treatment modeling strategy of ipw are combined in inverse probability weighted regression adjustment (ipwra) and the augmented inverse probability weighting (aipw). In the ipwra method inverse probability weights are used in the ra estimation to correct for misspecification in the regression function. If the regression function is correctly specified the weights do not affect the estimations. In the aipw method the treatment model includes a term that corrects this model if this model is misspecified. In using both the ipwra and the aipw the overlap assumption needs to hold, i.e. all observation must have a non zero probability of treatment. This requirement may be critical for the estimations (see also

below). If the overlap assumption holds, both the ipwra and aipw estimations have the double-robust property for some functional form combinations, saying that if either the outcome model or the treatment model is correctly specified, impacts are consistently estimated.

The basic intuition behind matching techniques (nearest neighbor matching (nn) and propensity score matching (ps)), is that outcomes are compared of observations that are as similar as possible, with the only exception of their treatment status. In nearest neighbor matching (nn) the similarity of observations with multiple covariates is calculated by constructing the distance between pairs of observations in terms of these covariates. Different scales of covariates and correlation between covariates is dealt with by calculating the so-called Mehalanobis distance. For removing large sample bias that arises because no formal outcome or treatment model is specified, a bias correction term needs to be included in the estimations in case of more than one continuous covariate. In propensity score matching (ps) a model of the probability of treatment (propensity score) is estimated. The sample is stratified in such a way that each stratum covers a subset of observations with similar characteristics. Impacts are calculated by comparing treatment and control observations within each stratum and subsequently use stratification weight to construct the aggregate impact. The treatment effects are calculated on the basis of matching the estimated probability of treatment.

We use these methods to estimate the treatment effect of combinations of crop cultivation, fertilizer use and livestock. A few choices need to be specified: in the ipwra and aipw estimations the outcome model is linear since the outcome variable is continuous and the treatment model is probit since the treatment variable is binary. In the estimations we use all exogenous variables as explanatory variables in the outcome model, as explanatory variables in the treatment model, and

as matching variables in both nearest neighbour estimation and estimation of the propensity scores. An overview of these variables is supplied in the appendix.

Table 3 Impacts on productivity in local maize cultivation using matching techniques

Dependent variable: natural logarithm of harvested local maize in kg per cultivated hectare by plot

	(1)	(2)	(3)	(4)	(5)	(6)
impact estimation method*	ra	ipw	ipwra	aipw	nn	ps
mono cropping	0.281	0.272	0.280	0.282	0.259	0.272
	(11.4)	(10.7)	(11.1)	(11.1)	(10.1)	(10.1)
mixed: local with hybrid maize	-0.299	-0.255	-0.233	-0.285	-0.321	-0.164
	(2.8)	(3.1)	(2.6)	(2.8)	(3.8)	(2.6)
mixed: local maize with groundnut	-0.009	-0.009	-0.008	-0.007	-0.021	0.017
	(0.2)	(0.2)	(0.2)	(0.2)	(0.5)	(0.4)
mixed: local maize with beans	0.203	0.238	0.210	0.208	0.239	0.211
	(4.8)	(5.9)	(5.1)	(5.0)	(5.9)	(4.7)
mixed: local maize with sorghum	-0.573	-0.598	-0.598	-0.583	-0.515	-0.539
	(10.4)	(7.6)	(10.5)	(10.3)	(9.3)	(8.0)
mixed: local maize with pigeon peas	-0.323	-0.323	-0.322	-0.321	-0.293	-0.274
	(10.4)	(9.7)	(9.4)	(9.9)	(9.6)	(5.4)
mixed: local maize with nkhwana	-0.069	-0.064	-0.065	-0.067	-0.063	-0.083
	(1.7)	(1.6)	(1.7)	(1.7)	(1.4)	(2.0)
fertilizer: chemical	0.464	0.471	0.466	0.466	0.439	0.463
	(16.9)	(16.9)	(16.9)	(16.9)	(15.2)	(15.6)
fertilizer: manure	0.106	0.111	0.108	0.107	0.109	0.121
	(3.1)	(3.3)	(3.2)	(3.2)	(3.0)	(3.4)
livestock	0.224	0.245	0.230	0.235	0.204	0.218
	(8.6)	(7.9)	(8.6)	(8.1)	(7.5)	(7.6)
number of observations	5768	5768	5768	5768	5768	5768

Notes – The table reports the population average treatment effect of the treated (ATE). Absolute *z*-statistics are given in parentheses (.) below the coefficient and are based on Abadie Imbens robust standard errors. The impact estimation methods are: ra = regression adjustment; ipw = inverse probability weighting; ipwra = inverse probability weighted regression adjustment; aipw = augmented inverse probability weighting; nn = nearest neighbour matching and ps = propensity score matching. In the nn estimations and following other authors (Abadie and Imbens, 2002) we use 4 matches for each observation. A bias corrected matching estimator is used for the continuous covariates, exact matching is imposed for a as many categorical variables as possible (before the estimation disintegrates) and heteroscedasticity consistent standard errors are calculated.

The estimation results summarized in Table 3, confirm most what is expected: *mono cropping*, *local maize–bean* cultivation, *chemical fertilizer*, *manure* and *livestock* all have a positive impact that is statistically significant. *Chemical fertilizer* has the largest impact, more than twice as large as *livestock*, and *local maize–bean* cultivation, which are both in the same order of magnitude. The impact of manure is around half as large as the impact of livestock. It should be noted that the

concept of manure in IHS-3 covers a combination of livestock manure and crop wastes (and is therefore less useful for the purpose of our investigation). On the other hand, and in contrast with the livestock variable, manure is defined at the plot level.

Some crop combinations, notably *local maize–sorghum*, and *local maize–pigeon peas* generate statistically significant negative impacts on local maize production per hectare. The estimated negative impacts is important since some of these crops combinations (e.g. *local maize–pigeon peas*) are claimed to be beneficial to maize yields. Finally, crop combinations *local maize–groundnuts* and *local maize–nkhwana* are insignificant or only weakly significant.

In the estimations of Table 3 we have made a drastic simplification: we have refrained from estimation with interactions of the explanatory variables. In the elaboration of the estimation framework, we explained that such a simplification disguises important synergies of inputs in agriculture: we need to interact key inputs in agriculture to reveal these synergies. Therefore we proceed by running estimations that identify four crop combinations, each with or without chemical fertilizer, and with and without livestock, implying a total of 16 interactions or 4 alternatives per crop combination. On the basis of the estimations of Table 3, the evidence from the literature and the objective of this research, we select the crop combinations *local maize–ground nuts*, *local maize–beans* and *local maize–nkhwana* apart from *local maize mono culture* for further investigation. In the estimations the excluded category is "non-fertilized, without livestock and a non-identified crop combination". The results of the estimations with interactions are reported in Table 4 for the full sample and in Table 5 for the major crop season covered in IHS-3, 2009-2010.

From the tables we observe that a statistically significant ATE with a positive sign for *fertilized local maize–bean* and *fertilized mono cropping*, either with or without livestock.

Fertilized local maize–groundnuts and *fertilized local maize–nkhwana* also has a statistically significant positive ATE, but only with livestock. The size of the estimated ATE is highest and very similar (see also below) for *fertilized local maize mono culture with livestock* and *fertilizer local maize–bean with livestock*. ATEs for *fertilized local maize–bean* and *fertilized mono cropping*, both without livestock and *fertilized local maize–groundnuts* and *fertilized local maize–nkhwana* both with livestock, is close to half as large. *Not fertilized with livestock* has a statistically insignificant ATE for all crops, and *not fertilized without livestock* is has a statistically significant negative ATE, also across all crops.

Next, we come to the assessment of these estimations. If we consider the estimated average treatment effects reported in Table 4 and 5, we observe that all estimated ATEs[23] of "not fertilized" alternatives are either insignificant or have a statistically significant negative sign. There is possibly one exception – nkhwana, unfertilized, with livestock, using regression adjustment estimation has a weakly significant positive ATE – but this result is not observed with other estimation methods. With the large sized statistically significant negative ATEs we cannot but conclude that not using chemical fertilizer clearly has a strong negative impact on local maize production per hectare. This observation is not new, but nevertheless an important implication of these estimations.

[23] Quite a substantial number of ATEs of unfertilized alternatives could not be estimated due to a violation of the overlapping assumption.

Table 4 Impact of combinations of chemical and organic inputs using matching techniques

Dependent variable: natural logarithm of harvested local maize in kg per cultivated hectare by plot						
	(1)	(2)	(3)	(4)	(5)	(6)
impact estimation method	ra	ipw	ipwra	aipw	nn	ps
local maize, mono cropping						
fertilized, livestock	0.484	0.549	0.453	0.490	0.487	0.464
	(12.0)	(7.4)	(11.4)	(4.5)	(12.5)	(11.3)
fertilized, no livestock	0.259	0.254	0.243	0.246	0.248	0.237
	(9.1)	(9.2)	(8.3)	(8.3)	(8.8)	(7.5)
not fertilized, livestock	0.024	0.020	0.020	0.002	0.007	0.036
	(0.3)	(0.3)	(0.3)	(0.0)	(0.1)	(0.4)
not fertilized, no livestock	-0.270	-0.234	-0.259	-0.262	-0.248	-0.232
	(6.5)	(5.5)	(6.1)	(6.0)	(6.2)	(5.1)
local maize–beans mix						
fertilized, livestock	0.436	0.457	0.483	0.478	0.404	0.431
	(6.8)	(8.6)	(9.5)	(8.9)	(5.8)	(8.5)
fertilized, no livestock	0.271	0.277	0.273	0.284	0.245	0.252
	(4.6)	(4.2)	(4.9)	(5.0)	(4.2)	(4.1)
not fertilized, livestock	-0.028	*	*	*	-0.070	*
	(0.1)				(0.3)	
not fertilized, no livestock	-0.582	-0.453*	-0.730	-0.695	-0.788	-0.555
	(4.6)	(4.2)	(6.5)	(5.2)	(6.6)	(5.1)
local maize–groundnuts mix						
fertilized, livestock	0.189	0.200	0.145	0.153	0.193	0.165
	(3.0)	(2.8)	(2.6)	(2.3)	(2.3)	(2.5)
fertilized, no livestock	0.017	0.082	0.039	0.032	-0.023	0.043
	(0.3)	(1.7)	(0.8)	(0.6)	(0.4)	(0.6)
not fertilized, livestock	-0.205	*	*	*	-0.119	*
	(1.9)				(0.9)	
not fertilized, no livestock	-0.418	-0.407	-0.380	-0.388	-0.654	-0.405
	(3.5)	(4.0)	(3.6)	(3.6)	(3.6)	(4.1)
local maize–nkhwana mix						
fertilized, livestock	0.266	0.306	0.258	0.279	0.298	0.258
	(3.5)	(5.2)	(3.4)	(3.3)	(3.7)	(2.8)
fertilized, no livestock	0.005	-0.031	0.010	0.007	-0.100	-0.059
	(0.1)	(0.5)	(0.2)	(0.1)	(1.3)	(0.8)
not fertilized, livestock	0.018	*	*	*	0.029	*
	(0.1)				(0.1)	
not fertilized, no livestock	-0.517	-0.571	-0.510	-0.502	-0.583	-0.594
	(5.8)	(7.6)	(6.8)	(6.4)	(6.6)	(6.6)
number of observations	5768	5768	5768	5768	5768	5768

Notes – The table reports the population average treatment effect of the treated (ATE). Absolute *z*-statistics are given in parentheses (.) below the coefficient and are based on Abadie Imbens robust standard errors. The impact estimation methods are: ra = regression adjustment; ipw = inverse probability weighting; ipwra = inverse probability weighted regression adjustment; aipw = augmented inverse probability weighting; nn = nearest neighbour matching and ps = propensity score matching. In the nn estimations and following other authors (Abadie and Imbens, 2002) we use 4 matches for each observation. A bias corrected matching estimator is used for the continuous covariates, exact matching is imposed for a as many categorical variables as possible (before the estimation disintegrates) and heteroscedasticity consistent standard errors are calculated.

* using the standard specification in terms of explanatory variables generated a violation of the overlapping assumption in these estimations. These results illustrate that ra and nn estimation breaks down more slowly than ipw, ipwra, aipw and ps estimation.

Table 5 Impact of combinations of chemical and organic inputs: crop season 2009-10

Dependent variable: natural logarithm of harvested local maize in kg per cultivated hectare by plot						
	(1)	(2)	(3)	(4)	(5)	(6)
impact estimation method	ra	ipw	ipwra	aipw	nn	ps
local maize, mono cropping						
fertilized, livestock	0.488	0.540	0.417	0.480	0.489	0.472
	(10.0)	(2.0)	(9.0)	(1.9)	(11.3)	(8.2)
fertilized, no livestock	0.261	0.254	0.253	0.254	0.260	0.236
	(8.3)	(7.8)	(7.9)	(7.9)	(8.4)	(6.7)
not fertilized, livestock	0.076	0.078	0.083	0.080	0.037	0.059
	(1.1)	(1.1)	(1.2)	(1.1)	(0.5)	(0.6)
not fertilized, no livestock	-0.282	-0.266	-0.263	-0.270	-0.245	-0.227
	(6.0)	(5.0)	(5.4)	(5.3)	(5.3)	(5.0)
local maize–beans mix						
fertilized, livestock	0.438	0.374	0.444	0.451	0.416	0.357
	(5.6)	(5.9)	(7.0)	(6.6)	(5.2)	(4.7)
fertilized, no livestock	0.284	0.292	0.264	0.275	0.253	0.317
	(4.1)	(4.4)	(41)	(4.1)	(3.7)	(4.7)
not fertilized, livestock	**	*	*	*	-0.058	*
					(0.2)	
not fertilized, no livestock	-0.698	*	-0.817	-0.832	-0.852	-0.780
	(4.7)		(6.9)	(5.0)	(6.6)	(4.9)
local maize–groundnuts mix						
fertilized, livestock	0.189	0.221	0.184	0.177	0.195	0.174
	(2.9)	(3.2)	(3.2)	(3.0)	(2.2)	(2.3)
fertilized, no livestock	-0.061	-0.070	-0.054	-0.065	-0.071	-0.079
	(1.0)	(1.3)	(0.9)	(1.1)	(1.1)	(1.0)
not fertilized, livestock	-0.360	*	*	*	-0.243	*
	(2.0)				(1.7)	
not fertilized, no livestock	-0.466	-0.450	-0.467	-0.457	-0.706	-0.535
	(3.4)	(3.6)	(4.1)	(3.5)	(3.4)	(4.5)
local maize–nkhwana mix						
fertilized, livestock	0.184	0.143	0.158	0.152	0.267	0.248
	(2.1)	(1.2)	(1.8)	(1.5)	(3.1)	(3.5)
fertilized, no livestock	-0.051	-0.025	-0.025	-0.036	-0.128	-0.029
	(0.7)	(0.4)	(0.3)	(0.5)	(1.5)	(0.4)
not fertilized, livestock	0.209	-0.333	*	*	0.047	*
	(1.7)	(1.0)			(0.2)	
not fertilized, no livestock	-0.598	-0.574	-0.613	-0.602	-0.595	-0.540
	(5.5)	(6.2)	(7.1)	(5.9)	(5.9)	(7.8)
number of observations	4606	4606	4606	4606	4606	4606

Notes – see previous table

* using the standard specification in terms of explanatory variables generated a violation of the overlapping assumption in these estimations.

** non concave solution in optimization.

Another feature of the estimated treatment effects in Table 4 and Table 5 that deserves to be mentioned is the large ATEs of *fertilized, livestock* cultivations and (the most likely statistically significant and) large difference between the ATEs of *fertilized, livestock* cultivations versus *fertilized, no livestock* cultivations. Under *mono cropping* and *local maize–beans* mix the *fertilized, livestock* ATE is up to twice as high as the *fertilized, no livestock* ATE. Under *local maize–groundnuts* mix and *local maize–nkhwana* mix the *fertilized, no livestock* ATEs vanish to zero, while the *fertilized, livestock* ATEs are statistically significant and of substantial size. One may question whether the livestock variable is an appropriate approximation for the use of animal manure in local maize cultivation. Possibly the variable merely distinguishes rich from poor farmers, or some other characteristic. Whatever is the case, the difference is large. Hence, these observations are interesting and useful, and deserve further investigations.

Finally, the results make us confident about the beneficial impact of *fertilized local maize–bean* cultivation and *fertilized local maize mono cropping*. ATEs are statistically significant, positive and consistently large, independent of the estimation method implemented. We investigate the relative size of these ATEs below.

Testing hypotheses

We are particularly keen to compare the performance of organic inputs relative to mono cropping. We focus on the following two questions:

1. Are there combinations of chemical fertilizer, livestock and local maize crop combinations that have a similar or higher treatment effect than fertilized local maize mono cropping? The evidence supports complementarity of chemical fertilizer and organic inputs if this is the case.

2. Are there combinations of organic inputs *without chemical fertilizer* that have a significant positive treatment effect and what is the size of this treatment effect relative to fertilized mono cropping? Answer to this question sheds light on the issue if and to what extent organic inputs are effective substitutes for chemical fertilizer.

The second question is, in fact, already answered in the assessment of the estimation results. Not using chemical fertilizer clearly has a strong negative impact on local maize yields. The estimation results do not suggest that organic inputs are capable of being effective substitutes for chemical fertilizer. A statistical exercise to test is ATEs are statistically different is superfluous.

The first question is investigated by comparing with a formal statistical test if the ATEs of fertilized local maize mono-culture are equal, higher or lower than the ATEs of fertilized local maize-bean, local maize-groundnuts and local maize-nkhwana cultivation. Relevant ATEs are the coefficients of the upper two rows for each crop combination in Table 4 and Table 5. Table 6a and 6b report the test results of comparing mono cropping with mixed cropping / organic cultivation: the upper part, Table 6a, compares fertilized mono cropping *with livestock*, with mixed cropping / organic cultivation, and Table 6b does the same for fertilized mono cropping *without livestock*. The table shows the t-test statistic if the difference between ATEs is equal to zero (H_0: d=ATE(mono culture)–ATE(organic inputs)=0). Next, p-values are shown for alternative hypotheses that the difference is below, unequal to or above zero (respectively H_a:d<0; H_a:d≠0 and H_a:d>0). The table reports test results from the nearest neighbour matching estimations: the other estimation methods generate similar test results (available on request from the author).

Table 6a Testing coefficients: organic inputs versus mono-culture, both fertilized*

	versus local maize mono cropping, fertilized, with livestock			
	|t|	P(d<0)	P(d=!0)	P(d>0)
local maize–beans mix, fertilized, with livestock	**0.8**	0.788	0.424	0.212
local maize–beans mix, fertilized, no livestock	2.9	0.998	0.004	0.002
local maize–groundnuts mix, fertilized, with livestock	2.9	0.998	0.003	0.002
local maize–groundnuts mix, fertilized, no livestock	7.0	1.000	0.000	0.000
local maize–nkhwana mix, fertilized, with livestock	2.3	0.989	0.022	0.011
local maize–nkhwana mix, fertilized, no livestock	6.5	1.000	0.000	0.000

Notes – The table reports tests on the difference of ATEs of organic inputs and ATEs of mono cropping (d = ATE(mono culture) – ATE(organic inputs), based on nn estimations (column 5, Table 7)

Table 6b Testing coefficients: organic inputs versus mono-culture, both fertilized*

	versus local maize mono cropping, fertilized, no livestock			
	|t|	P(d<0)	P(d=!0)	P(d>0)
local maize–beans mix, fertilized, with livestock	1.8	**0.035**	0.069	0.966
local maize–beans mix, fertilized, no livestock	**0.1**	0.537	0.925	0.463
local maize–groundnuts mix, fertilized, with livestock	**0.7**	0.751	0.498	0.249
local maize–groundnuts mix, fertilized, no livestock	4.5	1.000	0.000	0.000
local maize–nkhwana mix, fertilized, with livestock	**0.1**	0.469	0.938	0.531
local maize–nkhwana mix, fertilized, no livestock	4.3	1.000	0.000	0.000

Notes – The table reports tests on the difference of ATEs of organic inputs and ATEs of mono cropping (d = ATE(mono culture) – ATE(organic inputs), based on nn estimations (column 5, Table 7)

We evaluate Table 6a and 6b by looking primarily at the first two columns (|t| and P(d<0)). From the upper panel we infer that have to reject the null that fertilized mixed cropping productivity is equal or higher than fertilized mono cropping, with the notable exception of fertilized local maize-beans mix, with livestock. The t-value suggest that the difference between productivity is not statistically different from zero. From the lower panel we infer that productivity of fertilized local maize-beans mix no livestock, fertilized local maize-groundnuts

mix with livestock and fertilized local maize-nkhwana mix with livestock is statistically equal to productivity of fertilized local maize mono cropping no livestock. Additionally, the probability that productivity fertilized local maize-beans mix with livestock is lower than productivity of fertilized local maize mono cropping no livestock is less than 5%. These test results support complementarity between organic inputs and chemical fertilizer. Our empirical investigations further support the agronomic research that proposes fertilized maize/bean intercropping as an attractive strategy for low input subsistence farming (see e.g. Snapp et al. 1998).

6. Potential growth under organic inputs and constraints to expansion

What if entire Malawi goes organic?

It is easy to impose high productivity estimates of successful organic input combinations on total (local) maize area and simulate impressive growth rates in aggregate local maize production. However, this is not a credible and useful exercise: demand for crops and the feasibility of input choices is likely vary by location. Hence, in order to take this geographical component into account and get a some measure of the magnitude of the potential for growth of applying organic inputs on a larger scale, we impose the district favourite organic input combination to all district plots, but only if such a crop cultivation is already practised in the district. Hence, for all plots, we have calculated production as the product of area and productivity, where productivity is replaced with "district average organic inputs productivity[24]" that is feasible in the district, in case observed productivity is lower than the feasible organic inputs productivity in the district.

The simulation is a conservative estimate of potential growth. In the first place this is because we have used (district) averages of organic inputs production per hectare, while the

[24] The organic inputs alternative is fertilized local maize with either beans, groundnuts or nkhwana with or without livestock, depending on what performs best in the district.

optimal organic inputs technology choice is not the (district) average, but the maximum. Additionally, the district-wise calculation is restrictive: district-to-district spill-overs are assumed not to exist. Consequently, application of the highest yielding organic technique throughout the country, or alternatively, the introduction of organic techniques in districts where the beneficial crop combinations are not cultivated altogether, are both impossible[25]. Non-zero district average organic inputs productivity for IHS-3 varies from 790 to 1630 kg per hectare (median around 1200), which is not high but still in many cases a substantial improvement compared to realised productivity. For constructing aggregates we have used survey weights available in each IHS, following standard practise (see e.g. Solon et al., 2013).

Table 7 Possible production growth under extended use of organic inputs

North	47.1% (31.1%)
Central	27.2% (19.4)
South	61.6% (34.4%)
Malawi	41.9% (26.3%)

Note to table: the table reports the simulated growth in % in aggregate local maize production relative to realized local maize production, if organic inputs are used on a larger scale and based on district averages of organic input yields. In brackets we show growth rates at the lower bound of the 95% confidence interval, assuming a normal distribution for organic inputs yields. Source: own calculations

The simulation results reported in Table 7 indicate a high potential growth of local maize production under full exploitation of organic input techniques. Distinct from the estimations of average treatment effects and the testing in the previous sections, these simulations constitute support in favour of organic inputs in their own right. Especially in the southern region, where poverty is highest, there is substantial potential for increasing local maize production. The evidence

[25] A few districts (Nkhatabay, Kasungu and Nkhotakota) have no organic input alternatives in the simulations.

suggest that the potential is lowest (and decreasing over the years) for the central region: the central region has succeeded in achieving a high level of local maize yield to a greater extent than other regions.

Constraints to use of organic techniques

The question arises why apparently beneficial yield increasing and low-cost technologies are not implemented on a larger scale already. Apparently there have been constraints to achieving these higher productivity levels. To investigate this we have isolated those households with typically low local maize yields, households for whom implementation of organic input technology should be attractive and, hence, households that can potentially benefit from conversion to organic input technology. Comparison of the characteristics of this group of households or plots with those households or plots outside this group that make use of organic inputs and have relatively high local maize yields, allows to highlight the major differences or test hypotheses on the backgrounds of "not having implemented attractive and feasible organic input technologies". For example, we may investigate if organic techniques are not applied because of a lack of information, knowledge and awareness, because of poverty and being trapped in subsistence mono cropping, because of (supply or demand) constraints in legume crops, because of too little manure from livestock, too little chemical fertilizer available or too little labour supply. At this stage we only investigate if and to what extent average characteristics differ: on the basis of the empirical comparisons we find – and these reflect the key constraints – that low productivity plots that may potentially realise a higher productivity with organic input technology, are substantially lower in labour input per hectare and number of livestock per hectare. Hence, IHS evidence supports labour and livestock to be constraints to organic input technology. In practise farmers will employ inputs up to the point where their contribution to net return is zero: hence, both labour and livestock is

apparently too expensive or unavailable for these households[26]. The identification of livestock and labour as key constraints to the use of organic inputs in Malawi is also confirmed by agronomic experts. Additionally, plots are on average larger (!), and acquired to a lesser extent through lease, rent or tenure contracts. The difference in plot size has a regional component as it is concentrated in the north and the south.

7. Summary and conclusion

Fertilizer is widely considered to be key to productivity growth in sub-Saharan Africa agriculture and thereby to economic growth in this region. However, imported chemical fertilizers in Africa are expensive and a cheap and sustainable local alternative appears attractive. In this study we have investigated if and to what extent the use of organic inputs contribute to productivity in sub-Saharan Africa. For this purpose we exploit plot data from the agricultural module of Malawi Integrated Household Survey (IHS-3) to investigate to what extent productivity of non subsidized local maize, the key staple food in Malawi, is determined by organic inputs and chemical fertilizer. Organic inputs are approximated with livestock and crop combinations. The empirical specification explicitly and deliberately takes account of interactions of organic inputs and chemical fertilizer. We compare organic input outcomes with mono-cropping. A number of crop combinations correlate positively with local maize productivity, notably *local maize–beans, local maize–groundnuts*, and less consistently, *local maize–nkwana*, and some crop combinations correlate negatively, most prominently *local maize–sorghum* and *local maize–cassava*. The evidence supports local maize productivity under *fertilized local maize–beans*, *fertilized local maize–groundnuts* and *fertilized local maize–nkhwana* mix to be equal to

[26] Our estimations are based on a production function approach: we do not model the behavior of farmers that is guided by the difference between expected revenue and production costs.

fertilized local maize mono-cropping. Simulations confirm considerable scope for growth of local maize production if organic inputs are used on a larger scale. In the south the potential increase in local maize production is particularly large. Limited availability of labour and livestock are likely constraints to the adoption of organic technologies in local maize cultivation and to achieving higher levels of production per hectare. In all estimations and calculations we have ignored revenue from complementary crops and benefits from soil conservation outside those resulting in increased maize yields.

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Appendix A Data, data sources and variable construction

We use data from the Integrated Household Surveys of Malawi (IHS-3). The data were kindly made available by the National Statistical Office in Zomba, Malawi and the Poverty Team of the Development Research Group of the World Bank.

In processing the data we made the following decisions on concepts and variables:

In converting harvested output to kgs, weights of several uncommon quantity units (pail, basket, cartload) are estimated on the basis of sales data. We define crop combinations as a combination of maize with another crop on the same plot. IHS-3 records up to a maximum of five crops on the same plot. A large part of households have only one plot. We have used GPS based plot area as opposed to farmer reported plot area (also available in IHS-3, see Carletto et al., 2013 for an assessment of the difference between GPS based and farmer reported plot area). Mono cropping, or mono culture agriculture, is defined as a single crop on a plot. Since our analysis focuses on local maize, only local maize mono cropping is relevant in our analysis. Note that we cannot identify *continuous* mono-cropping (and its alleged adverse impacts on the nutrient balance of the soil and soil fertility) or, conversely, year-by-year crop rotation systems. Number of livestock is the number of cattle, goats, sheep and pigs. This total number is either scaled to the size of household cultivated area by dividing with total cultivated area (in the naïve production function) or converted to a binary dummy. Labour used in the cultivation of the plot is split up in household labour and hired labour. Household labour is measured in labour hours, plot specific and specified by type of labour (preparatory, pre-harvest and harvest). Data on hired labour (number of days) are available at plot level. Access to labour is binary variable with a value 1 if labour is hired and zero elsewhere. Among the households that do not hire labour, we may identify restricted or no access to labour, and unrestricted access to labour on the basis of the household labour / cropland ratio.

Access to credit is a binary variable that has the value 1 if the household has access to credit and zero elsewhere. Households that have a loan are assumed to have access to credit. Additionally, in the spirit of Doss (2006), we have included households that did not report credit constraints (but simply felt no need to borrow). Households that do report credit constraints (request would be refused, too expensive, too much trouble, do not like to be in debt, do not know lender) are assumed to have no access to credit. Also households whose request for credit / loans are reported to be rejected are assumed to have no access to credit. Access to information is approximated with the number of visits of extension staff (field assistant) to the household. The number of visits is converted to a binary variable with a value zero in case of no visits and a value 1 in case of 1 or more visits. Access to market is approximated with the distance to the nearest daily market, two-weekly market, ADMARC market and tarmac road. Annual data on rainfall in mm from around 30 meteorological stations from the Department of Climate Change and Meteorological Services, Blantyre are used to scale the household rainfall data. The crop year is identified by the year of planting.

Appendix B Variables used in estimations

Table A1 Availability, type and level of variables in empirical estimations

	IHS-3
Plot level	absolute size of plot, size of plot relative to total household area, distance plot to home; texture & slope of plot, fertilizer, manure, crop combinations, household and hired labour, acquisition of plot
Household level	age, education and gender of household head, access to labour, access to credit, access to information, crop advise, livestock, rainfall
Community level	distance to tarmac road, daily market, weekly market and ADMARC market, community size
Survey level	crop year

Appendix C Number of observations

Table A2 Number of observations per cultivation type

	local maize, mono crop	local maize–beans mix	local maize–groundnut mix	local maize–nkhwana mix
fertilized, livestock	727 (599)	171 (131)	143 (116)	175 (128)
fertilized, no livestock	1302 (1027)	253 (177)	289 (232)	290 (215)
not fertilized, livestock	270 (227)	27 (23)	28 (24)	50 (39)
not fertilized, no livestock	709 (572)	76 (57)	71 (56)	168 (127)

Source: IHS-3, full sample (crop season 2009-2010 in brackets)

Appendix D Estimation results of a naïve production function

Table A3 Productivity in local maize cultivation: naïve estimation, no interactions

Dependent variable: natural logarithm of harvested local maize in kg per cultivated hectare by plot

	(1)	(2)
ln(rainfall)	0.504	0.492
	(10.6)	(8.9)
ln(plot size)	-0.406	-0.390
	(23.0)	(20.1)
ln(share of plot in total hh area)	0.069	-0.049
	(3.5)	(2.1)
ln(distance plot to homestead)	0.021	0.024
	(5.1)	(5.4)
mono cropping	0.272	0.190
	(7.3)	(4.7)
mixed: local with hybrid maize	-0.233	-0.305
	(3.2)	(4.0)
mixed: local maize with groundnuts	0.087	0.091
	(2.1)	(2.1)
mixed: local maize with beans	0.262	0.205
	(5.9)	(4.3)
mixed: local maize with sorghum	-0.278	-0.191
	(6.5)	(3.7)
mixed: local maize with pigeon peas	-0.157	-0.170
	(4.6)	(4.5)
mixed: local maize with nkhwana	0.071	0.096
	(1.9)	(2.3)
soil: sand	-0.100	-0.071
	(1.7)	(1.2)
soil: between sandy and clay	-0.011	0.038
	(0.2)	(0.7)
soil: clay	0.026	0.058
	(0.5)	(0.9)
inclination plot: slight	-0.019	-0.007
	(0.8)	(0.3)
inclination plot: moderate	-0.084	-0.078
	(2.1)	(1.8)
inclination plot: hilly	-0.013	0.079
	(0.2)	(1.1)
acquisition plot	0.198	0.128
	(3.8)	(2.3)
seeds: purchased	-0.244	-0.239
	(8.3)	(7.0)
fertilizer: chemical	0.419	0.392
	(17.0)	(14.8)
fertilizer: manure	0.091	0.098
	(2.9)	(2.9)
ln(total number of livestock)	0.041	0.045
	(8.1)	(7.8)

labour: hired	0.043	0.046
	(11.3)	(11.1)
labour: household	0.060	0.056
	(6.4)	(5.7)
household head: male	0.119	0.119
	(5.0)	(4.3)
household head: no education	-0.025	0.032
	(0.7)	(0.8)
household head: ln(age)	0.071	0.074
	(2.5)	(2.2)
household head decides	0.104	0.124
	(2.5)	(2.5)
access to information: FA visit		
access to information: advice receivd	0.099	0.098
	(4.5)	(3.9)
access to credit	0.120	0.080
	(5.0)	(2.9)
ln(distance / time to market)	-0.009	-0.006
	(2.7)	(1.5)
ln(distance to tarmac road)	-0.021	-0.019
	(4.4)	(3.8)
ln(community size)		0.025
		(2.2)
crop season, first	0.117	0.128
	(2.1)	(2.1)
crop season, second	-0.040	-0.030
	(0.8)	(0.6)
d household (k)	no	yes
Number of observations	5761	5761
Number of households with more than 1 local maize plot	878	878
F (.)	(35, 5725) 62.62	(845, 4915) 4.61
Prob > F	0.0000	0.0000
Adjusted R2	0.2724	0.3460
RMSE	0.80687	0.76499

Notes – The table reports estimations of productivity in local maize production. Productivity in local maize is defined as harvested local maize per hectare of cultivated land, measured at plot level. Explanatory variables are at plot level, household level, community level, district level and survey level. Data are extracted from Integrated Household Survey 3 (IHS-3, National Statistical Office (NSO)). Explanatory variables are either indicator variables (with values of 0 or 1) or variables transformed into natural logarithms, labelled ln(.). Further details on the definition of variables is given in Appendix A. Absolute *t*-statistics are given in parentheses (.) below the coefficient. Adjusted R2 is the coefficient of determination, adjusted for degrees of freedom, and RMSE is the Root Mean Squared Error.