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Tinkering on the periphery: Labour burden not crop productivity increased under no-till planting basins on smallholder farms in Murehwa district, Zimbabwe

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ABSTRACT

No-till planting basins are promoted using seed and fertiliser inputs as incentives for their widespread uptake in Zimbabwe. The short term effects of planting basins on crop yields and labour requirements were evaluated in an on-farm experiment over two seasons (2009/2010 and 2010/2011) in Murehwa district, Zimbabwe. The experiment was established on clay (Luvisols) and sandy soils (Lixisols), in two field types; outfields (degraded) and homefields (better managed fields). Fields closest to homesteads (homefields) typically receive most nutrients and preferential management, and are more fertile than outlying fields (outfields), with implications for crop production and nutrient use efficiencies. The fertiliser sub-treatments consisted of (a) no fertiliser (control), (b) 60 kg N + 3 t manure ha^{-1}, (c) 60 kg N ha^{-1} + 10 kg P ha^{-1} (SSP) and (d) 60 kg N ha^{-1} + 20 kg P ha^{-1} (SSP). In addition, a socio-economic survey was carried out to understand the diversity in resource ownership among farmers and to explore whether there was a relationship with uptake of planting basins. Results showed that field type, nutrient application and season had a significant effect on crop yields ($p < 0.001$); there was no significant effect of tillage practice. The largest maize grain yield of 5.6 t ha^{-1} was obtained with a combination of manure (3 t ha^{-1}) and 60 kg N ha^{-1} under conventional tillage; the equivalent treatment under planting basins yielded 4.6 t ha^{-1} in the 2009–2010 season. Rainfall was poorly distributed in 2010–2011 season and the same treatment gave the largest grain yield of 1.6 t ha^{-1} under conventional tillage and 1.2 t ha^{-1} under no-till planting basins. Land preparation under conventional tillage required 6 man days ha^{-1} while planting basins construction required 76.5 man days' ha^{-1} for the clay soils and 51.5 man days ha^{-1} for the sandy soils. Weeding in planting basins required 40% more labour compared with conventional tillage (12 man days ha^{-1}) due to greater weed densities associated with early years of no-tillage. Planting basins did not enhance moisture conservation in a the 2010–2011 season when rainfall was poorly distributed as shown by the smaller yields. The increased labour requirements suggested a major impediment to the uptake of planting basins even for farmers without livestock. Farmers differed greatly in resource ownership; four resource groups were identified based on land size, cattle ownership, labour availability and land utilisation. However, the practice of planting basins did not relate to resource ownership due to the incentives provided by the NGOs. Given that planting basins increased the labour burden but not crop yield, and that incentives cannot go on forever, widespread adoption by smallholder farmers seems unlikely.

1. Introduction

The barriers to improved crop productivity and food security in Zimbabwe centre on poor soil fertility status and climatic volatility (e.g. Rurinda et al., 2013; Rusinamhodzi et al., 2013), and these conditions are also true for much of southern Africa (Challinor et al., 2007). The situation is further compounded by the limited resources (land and capital) that smallholder farmers possess (Giller et al., 2006, 2011b). Cropping systems that improve

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soil moisture and nutrient cycling while being locally adapted to the socio-economic as well as biophysical circumstances of farmers are therefore desired (Rusinamhodzi, 2013). No-till planting basins have been promoted since the turn of the millennium to improve crop productivity, soil fertility and reduce hunger on smallholder farms in Zimbabwe (Mazvimavi and Twomlow, 2009; Ngwira et al., 2013). Planting basins are shallow structures roughly 30 cm long, 15 cm wide and 15–20 cm deep that are maintained each season in the same place (Twomlow et al., 2008). Seeds and other inputs such as lime, fertiliser, manure or compost are precisely placed in the basins. Inputs are placed close to the plant where they are most required leading to efficient uptake and use. The purpose of the practice is to disturb the soil only where the crop is established, leaving the surrounding soil untouched. Planting basins allow water to accumulate thus improving water infiltration and are often described as a water-harvesting technique similar to the *Zai* soil restoration system, a complex cropping system concentrating runoff water and manure in microwatersheds used in West Africa (Roose et al., 1999).

Theoretically, planting basins have potential to improve crop productivity due to water conservation and targeted nutrient application (Van Niekerk, 1974). However, moving from mouldboard plough to planting basins may entail substantial initial labour inputs for resource constrained farmers. Under low-input systems, labour is often the major input and is critical for timing operations; insufficient labour often leads to reduced land utilisation and late planting, leading to small yields (Giller et al., 2006; Muoni et al., 2013). For example, Nyamangara et al. (2013) reported that weeding in planting basins required double the labour in conventional tillage, and that weed growth and labour demand remained higher under planting basins tillage even after several years. Moreover, increased crop productivity under planting basins was only observed when adequate fertiliser application was achieved (Nyamangara et al., 2014). However, Mazvimavi and Twomlow (2009) observed that household labour availability did not influence adoption intensity of planting basins and might not be a major consideration for the practice.

Although planting basins are considered a form of conservation agriculture for the semi-arid regions and specifically for farmers without draught power in Zimbabwe (Mazvimavi and Twomlow, 2009), they have been promoted indiscriminately by NGOs and development practitioners using incentives to improve their uptake by smallholder farmers (Nyamangara et al., 2013). Such an approach has been considered necessary to stop the rampant land degradation and to address the persistent food insecurity status of smallholder farmers. However, this approach does not necessarily work for all farmers due to differences in resource endowment and locally prevailing biophysical barriers (Giller et al., 2011b). The combination of biophysical factors such as soil type and climate, socio-economic factors such resource ownership and access to markets determines farmers' production orientation within each locality (Rusinamhodzi, 2013). At farm level, limited labour and inadequate resources such as cattle manure or chemical fertilisers often force farmers to apply only on limited portions of the farm each year leading to heterogeneous soil fertility status across the fields (Mtambanengwe and Mapfumo, 2005; Tittonell et al., 2007). Therefore, efforts to bring improved management options need to recognise the wide diversity of farmers in terms of resource endowments, priorities and constraints as well as the broader institutional and policy environment in which they operate (Giller et al., 2011a)

The occurrence of the soil fertility gradients within smallholder farms i.e. the so-called homefields and outfields (Mtambanengwe and Mapfumo, 2005; Zingore et al., 2007a) is a local biophysical condition which may determine the performance and the fate of new technologies. Homefields are often closer to the homestead and have historically received more nutrient inputs (fertiliser and manure) than outfields and are characterised by high concentrations of available P and soil organic matter, and a pH conducive for crop growth (Zingore et al., 2007a). The soil fertility gradients caused by differences in previous resource allocation require adapted nutrient management strategies to improve nutrient use efficiency and crop productivity (Zingore et al., 2007b; Rusinamhodzi et al., 2013). New technologies aimed at improving crop productivity often performs differently in these field types thus field type should be an integral component of the experimental design aimed at assessing such technological performance on smallholder farms (Zingore et al., 2007a,b).

According to available literature, there is no sufficient and congruent scientific evidence on the suitability of planting basins to alleviate the short term constraints to increased crop productivity to warrant their widespread promotion under the smallholder farming systems of Zimbabwe. Therefore, an on-farm experiment testing two tillage practices i.e. conventional tillage and planting basins was established over two seasons (2009/2010 and 2010/2011) in Murehwa, Zimbabwe to measure crop productivity and labour input requirements of the two tillage systems. In this farming system, crop residues are strongly needed for animal feed in the dry season (Valbuena et al., 2012; Rusinamhodzi, 2013), which competes directly with the need to provide soil cover (Nyamangara et al., 2013).

2. Materials and methods

2.1. Site description

The experiment was established over two seasons (2009/2010 and 2010/2011) in Chikore (17°50′S, 31°35′E, 1301 m above sea level—masl) and Ruzvidzo (17°51′S; 31°34′E, 1300 m masl) villages located in Murehwa smallholder farming area, 80 km north east of Harare, Zimbabwe. Murehwa is located in agro-ecological region II (Vincent and Thomas, 1960) which receives annual rainfall of between 750 and 1000 mm in a unimodal pattern between November and April. Prolonged mid-season dry spells are common. The soils in the area are predominantly granitic sandy soils (Lixisols: FAO, 1998) of low inherent fertility with intrusions of dolerite derived clay soils (Luvisols; FAO, 1998) that are relatively more fertile (Nyamapfene, 1991). Previous preferential application of fertiliser and manure has created soil fertility gradients within farms, the so-called homefields and outfields (Mtambanengwe and Mapfumo, 2005; Zingore et al., 2007a). Cattle ownership varies widely among households (Zingore et al., 2007a). Other small livestock such as goats and local chickens are also important. Farmers who own cattle use manure together with small amounts of mineral fertiliser they can afford on small areas of the farm resulting in improved crop productivity. Maize (*Zea mays* L.) is the dominant staple crop while groundnut (*Arachis hypogaea* L.), sweet potato (*Ipomoea batatas* (L.) Lam.) and sunflower (*Helianthus annuus* L.) are important crops.

The communal grazing area is characterised by the Miombo woodland dominated by *Julbernardia globiflora* (Benth.) Troupin, *Brachystegia boehmii* (Taub.) and *Brachystegia spiciformis* (Benth.) (Mapaure, 2001). Grass species of the genus *Hyparrhenia* are predominant, and *Andropogon*, *Digitaria*, and *Heteropogon* spp. are also common species. *Sporobolus pyramidalis* (P.) Beauv., a grass of poor grazing quality often dominates in overgrazed areas and perennially wet 'vlei' areas of the veld. In the dry season, the grazing is often of poor quality both in amount and nutrient composition.

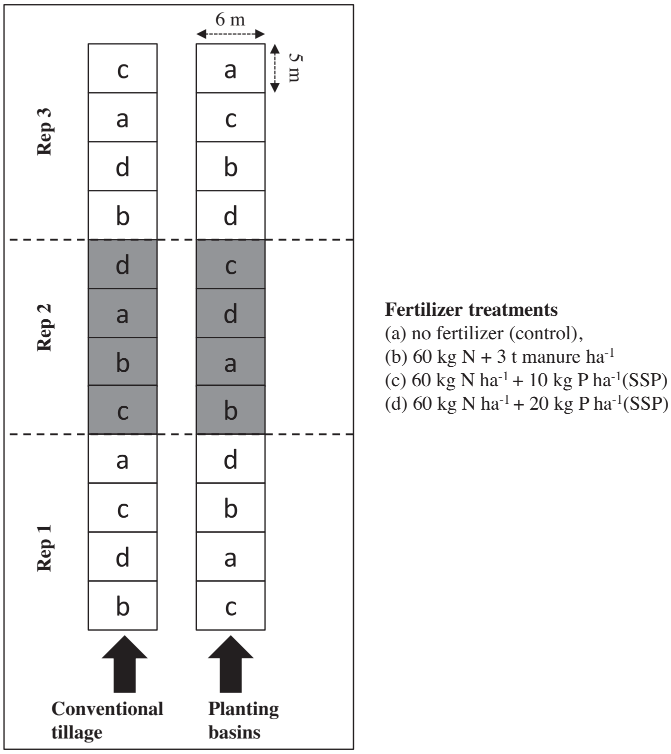

Fig. 1. A field layout of the tillage and nutrient management experiment established in 2009/2010 and 2010/2011 seasons at Murehwa, Zimbabwe.

2.2. Experimental design

The experiment was a split-plot design and replicated 3 times per field. A total of 12 experimental fields were used, 6 on clay soil and the other 6 on sandy soil. The 6 in each soil texture class were further subdivided into home fields and outfields i.e. 3 homefield clay, 3 outfield clay, 3 homefield sand and 3 outfield sandy fields. One set of homefield and outfield were located on each farm which means the experiment was established on a total of 6 farms. Previous field characterisation data reported by Zingore et al. (2007a) as well as farmer management practice details were used to select similar fields in each soil class. The major plots were for tillage management and minor plots were for fertiliser application (Fig. 1). Two tillage options were tested: (a) conventional ploughing with an ox-drawn mouldboard plough to a depth of 23 cm, planting hills of 90 cm × 30 cm were marked using a hand hoe after tillage, and (b) planting basins dug using a hand hoe, each basin was 15 cm (length), 15 cm (width) and 15 cm (depth), and were spaced at 90 cm between rows and 60 cm within rows. The experimental sub-plot measured 30 m^2 (6 m wide × 5 m long), enough to give between 6 and 7 rows of maize for each treatment. The homefields were previously under continuous maize cropping with good management i.e. received both fertiliser and manure. The outfields were mostly fallows which had been abandoned for about three to five years. The planting basins were dug each year from early August through October in the same positions for the two seasons. The fertiliser sub-treatments consisted of (a) no fertiliser (control), (b) 60 kg N + 3 t manure ha^{-1} (close to farmer practice), (c) 60 kg N ha^{-1} + 10 kg P ha^{-1} (SSP) and (d) 60 kg N ha^{-1} + 20 kg P ha^{-1} (SSP). The fertiliser/nutrient management treatments were developed based on what farmers in the study site were likely to afford. The maize plant population of 37 000 plants ha^{-1} was the same in both the conventional and planting basins treatments; two maize seeds were planted in each basin because of the larger spacing (90 cm × 60 cm) compared with conventional tillage (90 cm × 30 cm). Maize was planted on the same day for all the tillage treatments. The fields were not fenced and due to grazing in the dry season, soil surface cover by crop residues in the experimental fields was less than 10% in both seasons and no external mulch cover options were explored.

2.3. Crop yield and rainfall measurements

Rainfall was measured daily with a rainfall gauge at each farm close to the experimental fields and an average computed. Grain and above-ground biomass yield measurements were estimated from 3 rows × 2 m sub-plots in the centre of each plot after physiological maturity, this approach allowed the sampling of the same number of plants in the two tillage treatments. The maize plants were cut at 1 cm above ground and all biomass weighed. Grain was shelled from the cob by hand and separated from stover (leaves, stalk and core). Maize grain yield was calculated at 12.5% moisture content and stover on dry weight basis. Sub-samples for stover were taken and dried at 70 °C for moisture correction.

2.4. Labour data estimation

Labour requirements were estimated by direct observation for each whole tillage plot per farm (360 m^2), using the procedure described by Rusinamhodzi et al. (2012) where a regular team of farmers performed required activities on each plot at similar times of the day to reduce variations across farms. The most important activities were digging basins and weeding. Important recordings were: activity, start time, number of people, treatment, plot size and end time. The average labour times for each task for each tillage treatment were calculated and converted to man-days units (8 h) per hectare. Data from “farmers’ recall” from their own activities were not used because there were many confounding factors mainly related to planting densities, not having all treatments and the irregular nature at which farmers carried out their activities.

2.5. Farm diversity

Household socio-economic surveys were carried out in the two villages to understand the diversity of farmers in terms of resource ownership and crop residue management in relation to tillage management practices. A total of 80 of 120 households were interviewed across the two villages; respondents were selected randomly. The interviews were conducted at the farmer’s homestead with the assistance of local extension officers to understand landholdings, crop types, typical crop rotations, nutrient inputs, and tillage and crop residue management. Socio-economic characteristics included family size, labour availability, food availability and production orientation. Land utilisation was calculated as the ratio of land under crops to the total land owned by per farm.

2.6. Calculations and statistical analysis

The generalised linear mixed model (GLMM) in SAS 9.2 (TS2MO) of the SAS System for Windows© 2002–2008 was used to test the individual and interactive effects of tillage treatment, soil type, field type, fertiliser application and season on crop yield. The interactions tested were tillage × fertiliser, tillage × season, tillage × soil and season × tillage × fertiliser. In the analysis, tillage treatments and fertiliser application were considered fixed factors whilst season was considered as a random factor. A probability of 0.05 was used to test the significance of each factor. When the Fisher-test was significant, a least significant difference (LSD) test ($p \leq 0.05$) was used to separate the means.

Binary recursive partitioning was used to explore the variability of maize yield through constructing classification trees by splitting

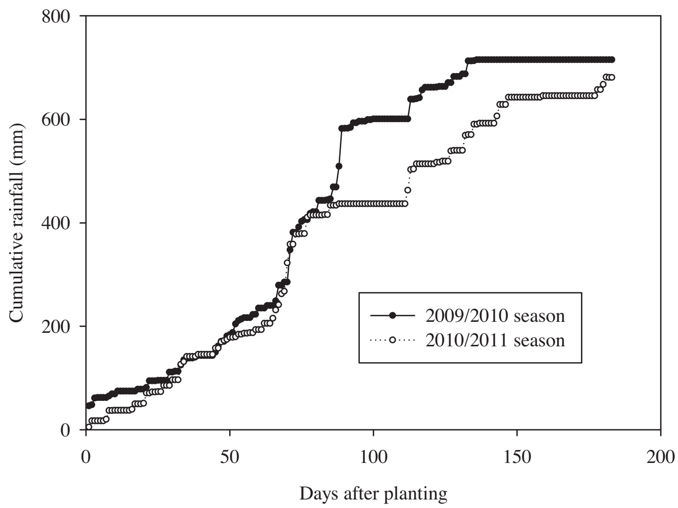

Fig. 2. Cumulative rainfall received during the two experimental seasons (2009/2010 and 2010/2011) at Murehwa, Zimbabwe.

the data into homogeneous binary subgroups or nodes based on soil type, field type, seasons, tillage and nutrient management strategies tested in the experiment. Node splitting was based on the Gini splitting rule:

$$Gini(t) = 1 - \Sigma_{ipi^2}$$

where p_i is the probability of class i in t (Apté and Weiss, 1997). The Gini splitting procedure finds the largest homogeneous category within the dataset and separates it from the remainder of the data; subsequent nodes are then identified the same way until further divisions are not possible (Buntine, 1992).

A principal components analysis (PCA) was performed to determine the household characteristics that were most important for explaining variability between farmers and for assigning farmers into different resource groups (McLachlan, 2005). A wealth index was used to categorise the households into to wealth classes or resource groups (RGs) using the procedure described by Cordova, 2009. Using the scores generated by the first principal component and the mean and standard deviation of the original data set, the wealth index of each household was computed using the formula:

$$W_j = \sum_{n=1}^{n} \left[\frac{\gamma_t \times \left(X_{ij} - \bar{X}_j\right)}{\sigma_t} \right]$$

where W_j is the wealth index for each household; γ_t represents the weights (scores) assigned to the n assets on the first principal component; X_{ij} is the original observation of asset i in household j, $\bar{X}_j$ is the mean holding of asset i in the sample and σ_t is the standard deviation of possessing each of the assets in the sample.

3. Results

3.1. Effects of experimental factors

The total rainfall received at Murehwa during the two experimental seasons were similar but the rainfall distributions within the seasons were very different (Fig. 2). Although dry spells during the two seasons occurred at similar days after planting, the cumulative rainfall by that stage was different. The dry spell in 2009/2010 season started when 200 mm more rainfall had been received compared to 2010/2011. Although both seasons had similar dry spell patterns, the 2009/2010 cropping season could be considered better by virtue of receiving more rainfall earlier in the season.

Table 1
Summary of the output of the generalised linear mixed model (GLMM) showing the influence on experimental factors (filed type, season, soil type, tillage and nutrient management) on maize grain yields over two seasons of on-farm trials in Murehwa, Zimbabwe.

Source	DF	*F* value	Pr > F
Model	95	14.1	<0.0001
Season	1	743.18	<0.0001
Field_type	1	11.34	0.0008
Soil_type	1	309.75	<0.0001
Tillage_management	1	4.96	0.0263
Nutrient_application	3	6.43	<0.0001
Season × nutrient_application	3	5.9	<0.0001
Season × tillage_management	1	0.57	0.4516
Season × tillage_management × nutrient_application	3	0.16	0.9768
Tillage_management × nutrient_management	3	0.34	0.8878
Soil_type × tillage_management	1	9.99	0.0016
Season × soil_type × tillage_management	2	49.58	<0.0001

Statistical analysis revealed that seasonal characteristics, field type, soil type, tillage and nutrient application were all significant ($p < 0.05$) on crop yield (Table 1). Of all the factors tested in the experiment, tillage management (planting basins or moudlboard ploughing) had the least effect on crop yield. The interactions of season × nutrient application, soil type × tillage, and season × soil type × tillage were all significant on crop yield. Decision trees constructed through the binary recursive procedure showed that seasonal characteristics were the most important factor (Fig. 3), suggesting that amount of rainfall and its distribution during the crop growth period had an overruling effect on yield. The second most important determinant of yield was soil type, yields from the red clay soils were often larger than those obtained on sandy soils for both seasons. In 2009–2010 season, nutrient application was more important than tillage, and field type was less important. In 2010–2011 season, field type was more important in defining crop yields than whether under conventional tillage or planting basins. Moreover, most of the terminal nodes (of the decision trees) under conventional tillage had larger yields compared to planting basins.

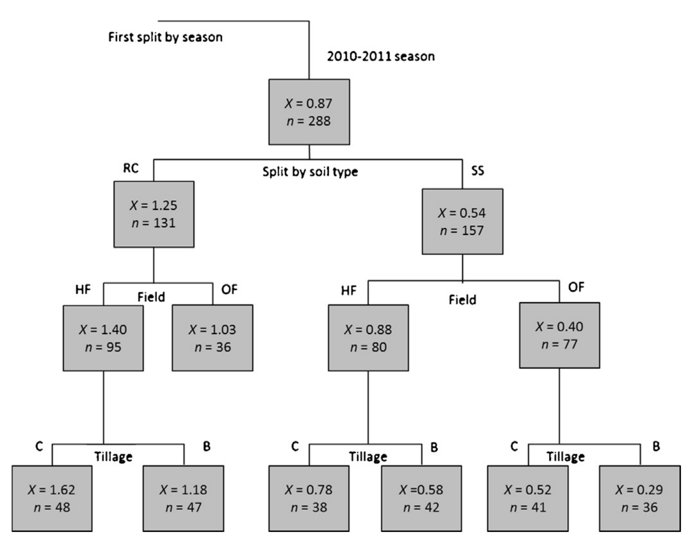

Fig. 3. The decision trees constructed by binary recursive partitioning rules for maize yield in 2009–2010 and 2010–2011 seasons (showing the 2010–2011 split). For each node, the average yield (*X*) and the number of cases (*n*) are given. The acronyms RC refer to red clay, SS to sandy soil, HF to homefield, OF to outfield, B to basins and C to conventional tillage.

Table 2
Maize grain yield as affected by soil type, field type, tillage practice and cropping season in Murehwa, Zimbabwe.

Soil type	Tillage	Nutrient application	2009–2010		2010–2011	
			Homefield	Outfield	Homefield	Outfield
Red clay	Basins	No input (control)	1.08	0.86	0.78	0.64
		60 kg N + 3 t manure ha^{-1}	4.63	3.66	1.58	1.37
		60 kg N + 10 kg P ha^{-1}	3.29	3.02	1.00	0.72
		60 kg N + 20 kg P ha^{-1}	3.84	3.13	1.27	0.90
	Conventional	No input (control)	1.05	0.72	0.85	0.51
		60 kg N + 3 t manure ha^{-1}	5.60	4.01	1.27	0.98
		60 kg N + 10 kg P ha^{-1}	3.68	2.86	1.03	0.77
		60 kg N + 20 kg P ha^{-1}	4.32	3.43	1.37	1.29
Sandy	Basins	No input (control)	0.52	0.40	0.45	0.21
		60 kg N + 3 t manure ha^{-1}	3.33	2.84	0.64	0.30
		60 kg N + 10 kg P ha^{-1}	2.03	1.92	0.51	0.26
		60 kg N + 20 kg P ha^{-1}	2.45	2.19	0.56	0.30
	Conventional	No input (control)	0.76	0.56	0.49	0.41
		60 kg N + 3 t manure ha^{-1}	3.42	2.39	0.78	0.75
		60 kg N + 10 kg P ha^{-1}	2.36	1.80	0.63	0.70
		60 kg N + 20 kg P ha^{-1}	2.90	2.21	0.92	0.88
		s.e.d.	1.2	0.8	0.3	0.2

3.2. Maize productivity

The effect of seasonal characteristics and nutrient application were apparent on crop yields but tillage management was not significant (Table 2). Homefields characterised by good previous management had larger yields compared to outfields across soil types and across seasons. The largest maize grain yield of 5.6 t ha^{-1} was obtained with a combination of 3 t of manure and 60 kg N ha^{-1} under conventional tillage; the equivalent treatment under planting basins yielded 4.6 t ha^{-1} in the 2009–2010 season (Table 2). Rainfall was poorly distributed in 2010–2011 season and the same treatment gave the largest grain yield of 1.6 t ha^{-1} under conventional tillage and 1.2 t ha^{-1} under no-till planting basins. The largest yield (5.6 t ha^{-1}) obtained was on a conventional tillage treatment whereas the smallest yield (0.2 t ha^{-1}) was on planting basins. Results showed that crop production without adequate nutrient inputs was not desirable on all tillage systems across soil types. In all the seasons and across the tillage treatments and field types, there was a significant yield response to P application (Table 2). The largest yield difference (between 10 kg P ha^{-1} and 20 kg P ha^{-1} application) of 0.64 t ha^{-1} was obtained in the first season under conventional tillage and red clay homefield. The smallest yield difference of 0.04 t ha^{-1} was obtained in the planting basins treatment in the second season under sandy outfields.

A comparison of tillage practices showed that on sandy soils, the overall result did not separate the tillage practices in 2010–2011 season although conventional tillage produced better yields in 2009–2010 season (Fig. 4a). In clay soils, conventional tillage was superior to planting basins in both 2009–2010 and 2010–2011 seasons (Fig. 4b). The gap in the seasonal mean yield was also widest on the clay soils than sandy soils suggesting that the yields on clay soils were predominantly water limited whereas those on sandy soils were nutrient limited.

3.3. Labour input in tillage systems

Conventional tillage using the mouldboard plough required 6.2 man days ha^{-1} in sandy soils whereas in clay soils, 9.4 man days ha^{-1} were required (Fig. 5). There were no differences in weeding requirements for the two soils types under conventional tillage. Digging planting basins required 51.5 man days ha^{-1} in sandy soils while an additional 25 man days were required to accomplish the same task in clay soils. Weeding requirements were significantly larger in planting basins than with conventional tillage, total weeding required 48.3 man days ha^{-1} under conventional tillage and 65.2 man days ha^{-1} with planting basins. The effect of soil type on weeding requirements in planting basins was not significant. On average moving from the mouldboard plough

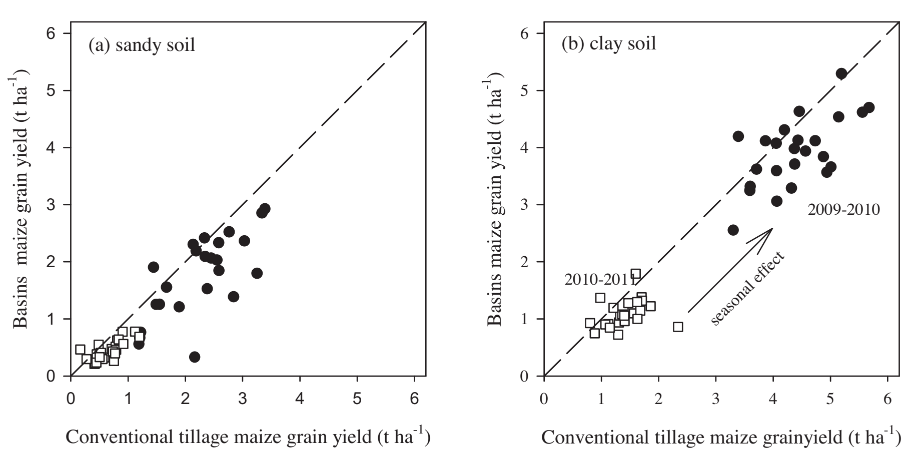

Fig. 4. Relative comparison between conventional tillage and planting basins maize grain yield in sandy soils (a) and (b) clay soils in Murehwa, Zimbabwe. The effects of season on maize grain yield is clear under both soil types but more apparent in the clay soils. Each data point represents maize grain yield for the four treatments from each field for the respective season i.e. 6 fields on sandy soil and 6 fields on clay soil.

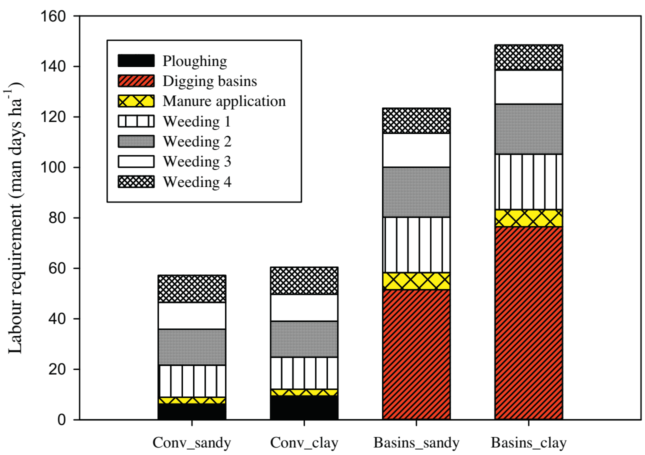

Fig. 5. Labour requirements for the two tillage systems tested on sandy and clay soil at Murehwa, Zimbabwe.

to planting basins entailed three times more labour input in maize production.

3.4. Diversity of farmers in relation to tillage practice

Principal components analysis showed that more than 83% of the variability in households in Murehwa was explained by the first five principal components, PC1 (31.3%), PC2 (19.7%), PC3 (15%), PC4 (9.9%) and PC5 (7.1%) which had eigenvalues greater than 1. The PC1 was strongly related to livestock ownership, land size, land cultivated and crop residues added to the field; PC2 was related to land utilisation and negatively related to the size of fallowed land; PC3 was strongly related to the labour size in the household and negatively related to the land/labour ratio; PC4 was related to the size of the family while negatively related to farmers' age, and lastly PC5 was strongly related to whether farmers sold labour (Fig. 6). Consequently, the most important characteristics for delineating farm types were land size, number of cattle, land utilisation and labour availability (PC1-PC5). The calculated wealth indices suggested four clear wealth categories or resource groups i.e. (a) $W < -1$, (b) -1 to 0, (c) 0 to 1, and (d) $1 < W$. The characteristics of the four resource groups identified in the study sites are summarised in Table 3. The richest farms had the largest number of all these attributes whereas the poorest did not own livestock, had the least land utilisation despite the smallest land size. The poorest to medium-poor constituted the largest number of farmers. The majority of farmers (82%) were underutilizing land due to a number of factors mostly related to poor market conditions for the main crop maize. Only 11 farmers (14%) were utilizing all their land and only 4% of the farmers had insufficient land i.e. they were renting in land (Fig. 7). Most of the under-utilised land is freely accessible to the community as grazing land.

Crop residue management in the site was both crop and field-based; it was possible that a farmer may collect all maize residues from a field close to the homestead but may leave all maize residues on a field far way. Due to this complexity in management, it was not possible to classify farmers based crop residue management as

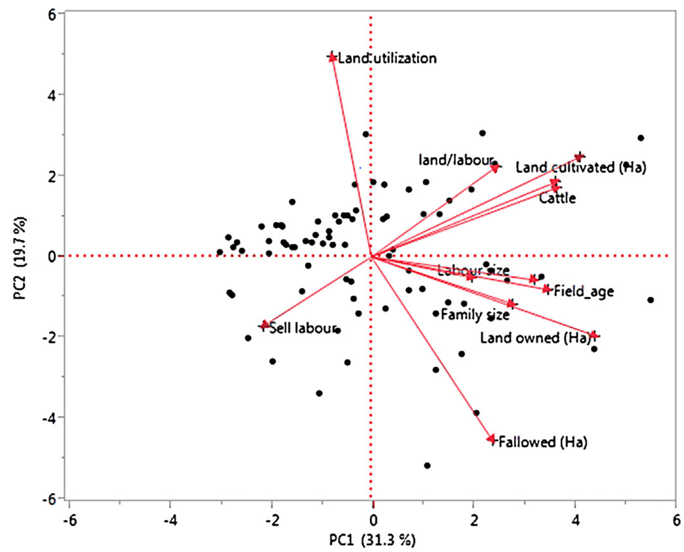

Fig. 6. The PCA-biplot showing the clustering of farmers based on collected socio-economic variables and resource ownership such as land size, cattle ownership and land utilisation in Murehwa, Zimbabwe.

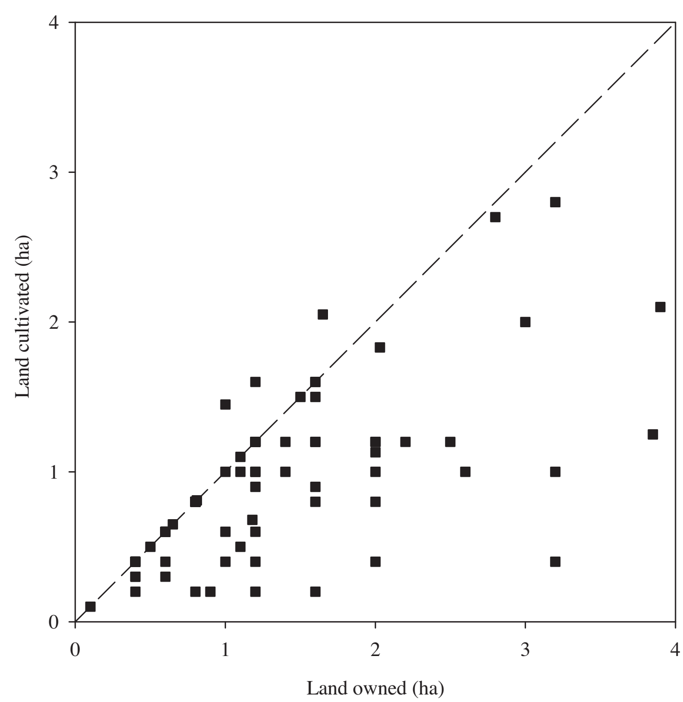

Fig. 7. Land utilisation in the study site, despite relatively small landholdings, the majority of farmers are not cultivating their land. The points above the 1: 1 line indicates that the farmer is hiring in land, below shows under-utilisation.

a single farmer could do all the possible crop residue management options on all of the field plots. Sorghum and finger millet residues were generally left in the field and burnt before the next crop. Maize crop residues were generally stacked and later used as livestock

Table 3
Selected characteristics of the resource groups in the study sites, numbers in parenthesis are the data ranges in that particular resource group.

Resource group	Households	Land owned (ha)	Cattle owned	Land utilisation	Labour availability
RG1	10	2.2 (1.0–3.9)	7 (0–13)	0.9 (0.3–1.5)	2.5 (1–6)
RG2	24	1.6 (0.4–3.9)	3 (0–7)	0.7 (0.1–1.2)	2 (1–4)
RG3	36	1.0 (0.4–2.6)	0.4 (0–4)	0.8 (0.1–1.3)	1.75 (1–4)
RG4	10	0.6 (0.1–1.2)	0	0.7 (0.2–1.0)	1.2 (1–2)

feed or for bedding in the kraal or left in the field especially for RG1 and RG2.

4. Discussion

4.1. Crop productivity

This study sought to explore the suitability of planting basins to alleviate the constraints of poor crop productivity and improve the livelihoods of farmers in Murehwa smallholder farming area of Zimbabwe. The analyses focussed on the short-term results which are important for farmers' decision making especially given that they are food insecure and vulnerable. If short-term yield benefits are not immediately attained, other benefits such as labour reductions especially with herbicide use are needed to cushion farmers against the initial investment. The experiments were established on soils representative of the dominant soil types under smallholder farming in southern Africa therefore the results reported here have broader applicability beyond the study sites. Whereas researchers and development agents seem to place much emphasis on managing tillage to improve productivity, the results from this study suggest that it is not important. A comparison of tillage practices on sandy soil did not reveal clear differences although planting basins appeared to produce better yields in a relatively drier season (Table 2). This result is similar to those reported by Nyamangara et al. (2014) based on comprehensive meta-analysis of maize grain yield results from tillage experiments established in the semi-arid parts of Zimbabwe. They further concluded that the yield performance of the tillage practices was mainly determined by how well the rainfall was distributed throughout the season. In clay soils, conventional tillage was superior to planting basins in both 2009–2010 and 2010–2011 seasons (Fig. 4b). The gap in the seasonal mean yield was also widest on the clay soils than sandy soils suggesting that the yields on clay soils were predominantly water limited whereas those on sandy soils were nutrient limited. The absence of a clear yield advantage on clay soils in years of different wetness suggested that the tested tillage options did not positively influence the ability of the crop to withstand long mid-season dry spells. Climatic-related differences have been observed to have a greater influence on the variation in yields (Dam et al., 2005). Planting dates for the two seasons were within a few days of each other across seasons thus year to year yield differences were attributed to rainfall variability.

Conventional tillage recorded the largest maize grain yield of 5.6 t ha^{-1} when a combination of 3 t of manure and 60 kg N ha^{-1} were applied; the same nutrient applications resulted in a yield of 4.6 t ha^{-1} in the 2009–2010 season (Table 2). Overall, the smallest yield (0.2 t ha^{-1}) was obtained from a planting basins treatment. Results showed that crop production without adequate nutrient inputs was not desirable on all tillage systems across soil types agreeing with results reported by Nyamangara et al. (2013). Previous management history was also significant on crop yield with fields that received good management (homefields) having greater yields than outfields with poor previous management. These results agreed with previous work on similar fields in the study area (Zingore et al., 2007b). The key to increased yield thus appear to be related to combined organic and chemical fertiliser application (Vanlauwe et al., 2010; Rusinamhodzi et al., 2013) in tandem with overcoming unfavourable climatic conditions.

Crop yields responded strongly to manure and P application across tillage treatments, in all field types and all the seasons, though the largest response was recorded in the first year of the experiment. Addition of manure is crucial for sustainable crop production on smallholder farms due to the addition of multiple nutrients including base cations and micronutrients, as well as soil organic matter accumulation which improves soil physical properties (Krull et al., 2004; Zingore et al., 2007b). Moreover, organic resources also improve the synchrony between nutrient release and crop demand which ensures high nutrient use efficiency (Handayanto et al., 1997; Nyamangara et al., 2003). The good crop yield response to N and P fertilisation underscored the importance of managing the nutrient deficiencies prevalent on most smallholder farms in Africa. The homefields, which are often associated with little or no response in crop yields because they often receive large quantities of fertiliser and manure (Vanlauwe et al., 2010), showed a good response suggesting that farmers may have been applying inadequate organic and mineral fertiliser prior to the experiment. On the other hand, the poor degraded outfields that are often non-responsive to fertiliser application due to multiple nutrient deficiencies and other physical limitations showed a good response in this study due to the benefits of the short-term fallowing, possibly due to the build-up of soil organic matter.

The amount of crop residue was insufficient soil cover to the soil due to grazing by livestock in the dry season and this was a major constraint to the practice of reduced tillage in the study site. Practicing no-till with inadequate mulch cover is considered worse than conventional tillage as the soil surface is likely to harden and impede rainfall infiltration and ultimately reduce crop yields (Thierfelder et al., 2013).

Nyamangara et al. (2013) reported that most smallholder farmers in Zimbabwe use one or two principles of CA due to a number of reasons, and this limits its performance at the field level. Previously, Rusinamhodzi (2013) reported that farmers preferred to feed crop residues to cattle and use manure for crop production in the same site. Although this practice is relevant to cattle owners who constitute 40% of the smallholder farmers, the communal nature of the grazing arrangement makes it very difficult for non-cattle owners to preserve their crop residues without investing additional labour. In the study sites and much of southern Africa, the sandy soils are dominant and it is important that for improved crop productivity, some form of organic matter inputs are needed to improve crop responses to nutrient application (Chivenge et al., 2011).

4.2. Labour dynamics

Shifting from conventional tillage to planting basins required more than double the labour input especially for land preparation. Similar results were reported by Nyamangara et al. (2013) who observed that producing crops using planting basins required a total of 85 man days ha^{-1} compared with a total of 39 days ha^{-1} for conventional tillage. Planting basins can be dug in the dry season well before the rains thus potentially spread the labour over several months, although the soil will be very hard, thus it is locally referred to as a dig- and- die technology (Andersson et al., 2011). However, most fields remain unfenced which means the basins may be destroyed by roaming animals during the dry season. Moreover, farmers prefer to produce vegetables both for food and market during the dry season thus there is a potential conflict in labour allocation between digging basins and vegetable production. Labour results suggested that it was more difficult to work on the clay soils compared to the sandy soils even though yield benefits are likely on clay soils, an additional 25 man days were required to dig basins on clay soils compared to sandy soils. The lack of differences in weeding requirements for the two soils types under conventional tillage appear to have been due to burying of weeds by the plough whereas with minimum tillage the weeds remain exposed on the surface (Muoni et al., 2013). Although soil inversion is an advantage in burying weeds and reducing weed pressure, it inevitably increases soil organic matter oxidation and the concomitant decline in soil health (Krull et al., 2004).

The exposure of weeds on the soil surface or shallow depth leads to significantly larger weed infestation and labour requirement in planting basins than with conventional tillage. Farmers generally use combined mechanical and hand weeding as the preferred and cheaper weed control methods, and use of herbicides is uncommon (Siziba, 2007). Thus the use of herbicides for immediate weed control though effective in combination with reduced tillage practices, is currently not within farmers reach (Muoni et al., 2013). The increase in labour requirement by a factor of up to three for already under-resourced farmers is a strong disincentive for the uptake of planting basins. Even with such significant labour input in constructing basins, it was observed in both seasons that the structures are destroyed by the first rains in sandy soils. The water collection role diminishes immediately unless they can be maintained throughout the season which entails even more labour. Although the technology promotion is targeted to farmers who do not own cattle in other regions, previous studies (e.g. Zingore et al., 2007a) have shown that these poorest groups need to work on richer farmers' fields for their livelihood. In certain circumstances labour is exchanged for tillage services, as conventional tillage reduces substantially the labour requirement for land preparation, thus the absence of draught power alone does not necessarily define the tillage options that the farmers will use. It is therefore unlikely that the poorest group of farmers will be able to utilise technologies that exacerbate their dire circumstances.

4.3. Farmers diversity in relation to tillage practice

Analysis of the socio-economic data revealed clear differences in resource ownership or wealth classes among famers and four broad resource groups (RGs) were identified. These results were in agreement with those reported by Zingore et al. (2007a) although they used a different approach in identifying the RGs. As is common in most crop-livestock systems, cattle ownership is considered the single most important indicator of wealth, and this site is no exception. This is due to the many functions that cattle are used for, especially their support for crop production through draught power for tillage, the importance of manure for nutrient inputs (Murwira et al., 1995; Rusinamhodzi et al., 2013), their use in cultural and traditional ceremonies, immediate food provision (milk and meat) as well as their use as insurance in times of need (Stroebel et al., 2008). Cattle ownership directly affected the amount of nutrients applied as well as the choice of tillage for farmers. Manure was more often applied byRG1 and RG2 farmers; some farmers in RG3 and RG4 mostly collected manure from the rangelands and applied it on smaller areas. Manure application for crop production is significant in this site because the average fertiliser application was found to be a maximum of 42 kg N ha^{-1} across RG1 and RG2 and virtually close to zero for the poorest farmers (RG4). Yet increased crop productivity under minimum tillage as in planting basins has been found under similar systems to be directly related to the amount of fertiliser that farmers can apply (Nyamangara et al., 2013).

Although farmers were diverse, their expectations from their field crop production activities were often similar. The majority of them lived on the edge of subsistence and expected improved food security, and income with less labour and input costs. Such expectations were found to be directly in conflict with yield and labour requirements reported in this paper. The technological boundaries for practicing planting basins seemed to revolve around farmers who did not own cattle (RG3 and RG4) because of limited tillage options, and their likelihood of getting free inputs compared to livestock owners. The indiscriminate promotion of planting basins currently a source of free fertiliser and seed inputs for farmers did not allow an analysis of the relationship between resource ownership and tillage practice. Thus the incentives from NGOs has impacted positively on the practice of planting basins, the corollary being that adoption by farmers was directly linked to the continued presence of NGOs. There was no relationship between farmer resource endowment and the practice of practice basins due to the free inputs provided by the NGOs. However the poorer farmers (RG3 and RG4) sold labour to the wealthier farmers (R1 and R2), and utilised the smallest proportion of their land which means that they were also unlikely to cope with the increased labour demands of planting basins.

4.4. Tinkering on the periphery

Previous studies from Zimbabwe's semi-arid regions suggest that well maintained structures such as planting basins may be needed to complement the little mulch in moisture retention (Mazvimavi et al., 2008; Mupangwa et al., 2008). However, results from this study suggested that tillage management was not an important driver of crop productivity and might not be priority for vulnerable small farmers. Thus the indiscriminate promotion of planting basins for small farmers is equated to 'tinkering on the periphery' i.e. not addressing the root cause of farmers' current constraints but instead creating new ones with no obvious solutions in sight.

This situation has persisted for long because scientists and development agents have concentrated more on output from the field in situations where inputs have been provided by NGOs (e.g. Marongwe et al., 2011) with little attention given to farmers' constraints and opportunities (Giller et al., 2009). In this study, both tillage practices received the same fertiliser application such that yield differences would have been attributed to better resource use, but this was not observed. If the real conditions of farmers are considered i.e. inadequate fertilisation and inability to access and use appropriate herbicides (Baudron et al., 2012), the yields reported here would have been much smaller. Recently, adequate and appropriate fertiliser application has been identified as an important additional principle in the practice of conservation of agriculture (Vanlauwe et al., 2014), although some authors do not agree (Sommer et al., 2014). It is evident that as long as farmers do not see practical solutions to the constraints they face, the technology is unlikely to succeed. Support systems related to the market conditions and the extent to which farmers participate in the market and information dissemination need to be reinforced for farmers to utilise new technologies (Sanginga and Woomer, 2009). The majority of farmers (82%) were underutilizing land despite small landholdings (0.3 ha to 3.9 ha) due to a number of factors mostly related to poor market conditions for the main crop maize (Table 3 and Fig. 6). These small landholdings suggest little scope for farmers to derive economic benefits from practicing reduced tillage. Although planting basins were practiced by about 98% of farmers in the study sites including farmers who own cattle, the maximum land size allocated to planting basins was only 0.2 ha per farm (equivalent to the inputs received), it was only 10% of the landholding at most. Such small landholdings where planting basins are practised are not likely to contribute significantly to household food security and income nor is it sustainable for NGOs to provide such inputs every season.

5. Conclusions

The conventional tillage practices led to larger yields when rainfall was better distributed throughout the season. On the other hand, the beneficial effects of planting basins on crop yield was not observed when rainfall was poor. Planting basins are likely to increase crop productivity if adequate fertiliser application, weeding and soil cover is achieved. The indiscriminate promotion of a technology without consideration of the farming system, its constraints and opportunities is futile as it does not provide the desired solutions i.e. it is equated to 'tinkering on the periphery'. This is because farmers differ widely in terms of resource ownership and consequently their capacity to meet the requirements of the new technology. Cattle ownership, land size, labour availability and land utilisation were some of the important attributes in delineating farmer resource groups (RGs) in the study site. The increased labour requirements suggested that it is unlikely that farmers will abandon the plough in favour of the hand hoe especially if they own cattle or are able to access tillage services from other farmers and there are no incentives. Given that planting basins increased the labour burden but not crop yield widespread adoption by smallholder farmers seems unlikely and new innovative pathways to sustainable intensification are needed.

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