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Intercropping in Zimbabwe conservation agriculture systems using a farmer-participatory research approach

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Smallholder farmers in sub-Saharan Africa (SSA) are under increasing pressure due in part to climate change and soil degradation, with many farming households unable to achieve even basic food self-sufficiency. Conservation Agriculture (CA) is a possible solution to these challenges, but the lack of sufficient biomass for mulch has limited wide-scale adoption, and many farmers who practice CA resort to adding supplemental mulch to their CA plots. Legume intercropping would not only provide biological and nutritional diversity, it may also provide an *in situ* cover, thereby reducing the amount of mulch required for soil and water conservation. Farmer managed research experiments were used in two semi-arid areas of Zimbabwe to test whether intercropping a cereal crop [maize (*Zea mays*)] with a legume [cowpeas (*Vigna unguiculata*), lablab (*Lablab purpureus*) or pigeon pea (*Cajanus cajan*)] could increase the total amount of biomass produced. The experimental design included two replicates with legume species and presence or absence of mulch cover as factors in the design. Maize yields were increased more by adding mulch than by legume intercrops in the absence of mulch. Therefore, intercrops were not a substitute for mulch. However, adding intercrops did significantly increase the amount of total biomass (maize and intercrop dry matter) produced at the sites and therefore, in addition to contributing protein rich grains, intercrops may reduce the amount of mulch required for soil and water conservation in CA systems. Farmer participation allowed the research to be conducted in the context of small-holder CA.

Key words: Intercropping, cowpea, lablab, pigeon pea, soil conservation, farmer-based research.

INTRODUCTION

The majority of crop production in Zimbabwe is based on subsistence agriculture implemented by resource-poor smallholder farmers. Most of this crop production is characterized by limited application of inputs (due to the high cost and limited availability of agricultural inputs including seeds, fertilizers and agricultural chemicals),

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deteriorating soil conditions (Vagen et al., 2005) and increasingly uncertain weather patterns (Sennhenn et al., 2017).

Conservation agriculture (CA), based on crop diversity, soil cover and limited soil disturbance (Kassam et al., 2015), has been widely promoted as a solution to these challenges (Steward et al., 2018). An analysis of 48,000 smallholder farmer plots in Zambia over 3 years found overall yield benefits of CA, but only when combined with early planting (Ngoma et al., 2015). Although, global meta-analyses of the effects of CA on agricultural yields are inconclusive and sometimes controversial (Brouder and Gomez-Macpherson, 2014; Giller et al., 2015; Pittelkow et al., 2015), positive impacts have been found to be more likely under drier conditions (Pittelkow et al., 2015), which is perhaps why the evidence from southern Africa tends to be more positive. A meta-analysis of CA studies in sub-Saharan Africa showed that while crop grain yields are significantly higher in CA systems, this is dependent on including both soil surface mulch and crop rotations: the two components that are, for many smallholder farmers in SSA, the bottlenecks to adopting CA (Corbeels et al., 2014).

Researchers and farmers have experimented with CA in Africa for at least fifty years (Kannegieter, 1967; Lal, 1974). In Zimbabwe, CA trials were conducted at research stations starting in the 1950's (Smith, 1988), with up to 30% use of CA on commercial farms before 2000 (AGRITEX, 2016). Brian Oldrieve, a commercial Zimbabwean farmer, began experimenting with CA systems for smallholders in the late 1980's (Blank, 2012). This system involved using manually dug planting basins and often the use of supplemental mulching material, and was promoted as a relief intervention and as a climate smart agriculture technology starting in the early 2000's (AGRITEX, 2016).

Organizations that promoted CA in Zimbabwe (FAO, ICRISAT, ACF and Foundations for Farming) also recognized the importance of soil cover to capture the full benefits of a CA system and thus encouraged farmers to cut and carry mulch onto their CA plots. This importing of residues from outside the farm is feasible on small areas, and is practiced mainly by smallholders in search of family food security, but is rarely feasible on larger areas due to the high labor demands (Grabowski and Kerr, 2014) and availability of biomass for mulching (Giller et al., 2009), owing partly to low maize yields and also competition from livestock (Mtambanengwe and Mapfumo, 2005). An additional biophysical challenge is high mulch decomposition rates from termites, which are sometimes more active in CA systems (Nhamo, 2007). Further, mulching only tends to be viable when property rights over residual crop biomass are observed and tenure is secure (Erenstein, 2003). A recent ex-post evaluation of an extensive and long-term (10+ years) program of CA promotion in Zimbabwe also identified lack of mulch as the biggest obstacle to increasing area and number of farmers practicing CA (Nkala, 2017).

These limitations around mulch have resulted in a situation where farmers recognize the value of CA but only practice it on a relatively small (typically ¼ to ½ ha) plot with the rest of their farm under conventional management. In 2015, approximately 300,000 farmers used CA in Zimbabwe but overall hectarage remained low due to the small average size of CA plots (AGRITEX, 2016). In areas with large numbers of CA farmers, mulch has become an increasingly valued commodity, with high levels of competition for biomass as livestock feed, thatching, mulch, etc.

One possible solution to this challenge of lack of mulch is intercropping the main cereal crop with a (leguminous) cover crop (Rusinamhodzi et al., 2011). For example, a study from Cameroon demonstrated that crop biomass production can be doubled by intercropping a secondary leguminous crop with maize (*Zea mays*) or sorghum (*Sorghum bicolor*), without a yield penalty for the cereal (Naudin et al., 2010). Similar studies in Zimbabwe have also found that legume intercropping can contribute significantly to the production of mulch for subsequent crops also without a yield penalty for the cereal crop (Baudron et al., 2012; Naudin et al., 2010). Adding an intercropped legume may also decrease mulch decomposition rates. Sanaullaha et al. (2011) found the decomposition of plant residues and soil organic matter is slower under drought conditions when plants are grown in mixture as compared to monocultures, while Palm et al. (2001) found that mixing of nitrogen (N) rich residues (for example from intercropped legumes) with N poor sorghum residues may reduce the carbon : nitrogen (C:N) ratio of the combined mulch, therefore avoiding potential problems of temporary N immobilization by micro-organisms. Some researchers believe CA can result in nitrogen immobilization, particularly in areas of low quality crop residues (Droppelmann et al., 2017).

While intercropping is a traditional and common part of farming systems in southern Africa, settler and missionary practices and policies zealously discouraged such practices (Page and Page, 1991). This has led to a situation where monocropping by smallholder farmers is now common across much of southern Africa (Snapp et al., 2002). The growing interest in introducing or re-introducing intercropping to these regions to address some of the challenges to agricultural production (Snapp, 2017) together with the continued interest in CA as a climate smart agricultural technology in the region has led to a slowly growing number of studies in recent years that have directly addressed the integration of intercropping into CA systems.

Despite the fact that some advocates claims that legume intercropping in CA systems can eliminate the need for adding supplemental mulch in semi-arid areas of Africa, scientific studies verifying this claim could not be found. This study, which compares the effects of adding three different legume intercrops to maize grown under a

CA system for smallholders in Zimbabwe, has therefore been implemented in part to gather preliminary evidence on whether intercropping a cereal crop with a legume can increase the total level of biomass produced and provide sufficient cover for the practice of CA without adding additional mulch in semi-arid areas. It is hypothesized in this study that the living plant growth of the legume intercrop will have the same positive effect on maize yield as dead plant residue mulch amounts typically used by small-holders in Zimbabwe. Further, it is hypothesize in this study that including an intercropped legume in maize based CA systems will increase the total amount of biomass (total dry weight of legume and cereal crop production) per unit area.

In order to maximize the benefit to farmers themselves and to collaboratively learn from the experiences of farmers, this study was conducted together with small-holder farmers directly on the farmer's own fields and managed collaboratively with the farmers.

MATERIALS AND METHODS

Study sites

This study was conducted with three farmers from two different areas of Zimbabwe (Figure 1). Farms in the Lupane region (sites J1 and J2) are in agro-ecological zone IV, characterized by a mean annual rainfall of 450 to 600 mm, and a mean annual temperature of 18 to 24°C. The rainy season in the Lupane region typically starts in November and ends in March. Soils in this area are in the Regosol group - deep Kalahari sands, with very deep levels (up to 75 m) of fine to medium grained sand, extremely low sand/silt concentrations and little or no reserves of weatherable minerals (Department of the Surveyor-General, Causeway 1979). These soils face two major limitations for agricultural purposes: their low nutrient reserves and the relatively high permeability and associated low water holding capacity (Nyamapfene, 1991). The farm in the Neshuro region was on the border between agro-ecological zones IV and V. Soils in this area are in the Fersiallitic group - grey brown to reddish brown sandy loams, with silt percentages between 10 and 20%, clay percentages between 30 and 60%, and appreciable reserves of weatherable minerals ((Department of the Surveyor-General, Causeway 1979). These soils are of very high agricultural potential, with the main limitation being the semi-arid local environment (Nyamapfene, 1991).

Experimental design

The experiment was initiated in late 2015 and was followed for one cropping cycle. Farmers were selected by the local Non-Government Organization (NGO) partner in conjunction with a research technician from the University of Manitoba. A two-replicate split plot experiment with eight treatments was conducted on each of the three farmers' fields; the main-plot treatments were mulch and no mulch, while the sub-plot treatments were legume cover crop species planted between the rows of the maize main crop. Each farmer managed trial was established on a piece of land approximately 40 m × 12 m while each treatment was 5 m × 6 m. Initially, there were 8 farmer managed trials in three different locations, however the data from five sites was judged as not reliable and was not used in this analysis. The major limitation of this study was that the design was not randomized; the decision to do this was to make it easier for farmers to manage (pseudo-replication).

The seed types used for each trial were provided for by the partner NGO. The maize (*Zea mays L.)* used was ZM 521 OPV: an intermediate variety (63-66 days anthesis, 121-132 days maturity), semi-flint grain maize bred by CIMMYT, who claim that it yields 30 to 50% more than traditional varieties under drought and low soil fertility (Capstone Seeds, 2016). The cowpea (*Vigna unguiculata L.)* used was CBC3 - an upright bushy variety, chosen because grain yield for upright varieties such as CBC3 have been found to be 2-4 times higher than for more traditional climbing varieties in maize cowpea intercrops, as well as reduce the amount of competition with maize (Mashingaidze and Katsaruware, 2010). The Lablab (*Lablab purpureus L.*) and pigeon pea (*Cajanus cajan* L.) seeds were procured locally by the project staff from OPV varieties currently in use by local farmers.

Farmers received a copy of the trial design with explanations in their local language on how to establish the trial. No conventional check treatment was included, as farmers are well aware of the performance of their traditional systems (Ramisch, 2014). Seeding dates varied between all plots depending on rainfall and irrigation opportunities. For many farmers, their first maize planted in 2015/16 died which needed to be reseeded 2-3 times in some but not all planting stations. The cowpea and lablab did not require replanting. However, poor germination of pigeon pea resulted in several farmers replanting with still poor levels of germination.

Mulch was added to the plots using locally available sources. As farmers were told to plant according to their standard practice, the type and amount of mulch added to the mulched plots varied between farmers (from ~ 4000 kg/ha at site J2 to ~14,000 kg/ha at site N4). Mulch type was predominately grass sedges at J1 and J2 and a combination of maize and millet stover and unpalatable grasses from local hills and velds. Planting date also varied according to the farmers' typical practice. At J1, maize was planted on Nov 25, 2015 and legumes on Jan 5, 2016. At J2, all crops were planted on Jan 12, 2016. At N4, all crops were planted on Jan 21, 2016.

Planting basins were dug with hand hoes, with the basins spaced either 60 cm × 90 cm apart (sites J1 and J2) or 75 cm × 75 cm apart (site N4). Basins were 8 to 10 cm deep. Three maize seeds were planted per planting basin, and thinned to leave an average of two plants per basin. Maize plant population was 37,087 plants/ha at J1 and J2 and 35,555 plants/ha at N4. Farmers added an equal amount of composted cow manure to all the planting stations (generally two handfuls). None of the farmers applied inorganic fertilizer. No herbicides or insecticides were used, although this was not a condition of the experiment. Intercrops were planted mid-way between the rows of maize with a 50 cm spacing between legume hills (30 plants plot^{-1}; 1 plant m^{-2}). Total soil disturbance is estimated at ~40%. Farmers managed the plot as per their usual practice which primarily included hand weeding.

Experimental design

The data was analyzed assuming a randomized complete block design (n=2), despite the fact that randomization on main-plots and sub-plots did not occur. Though not ideal, justification for using this approach hinges upon the value of using farmers as research partners, and preliminary evidence for a concept, not conclusive results, is been looked for. Therefore, the results should not be interpreted as conclusive but as simply giving a preliminary response to the hypothesis.

At time of maize maturity, intercrop biomass and yield and maize biomass and yield were all determined from plant samples collected from a two-meter row section sample (one/treatment rep). Samples were stored in very porous canvas bags until air dry and then weighed with an electronic laboratory scale. Lablab and pigeon pea are both medium to long season crops, and therefore were still

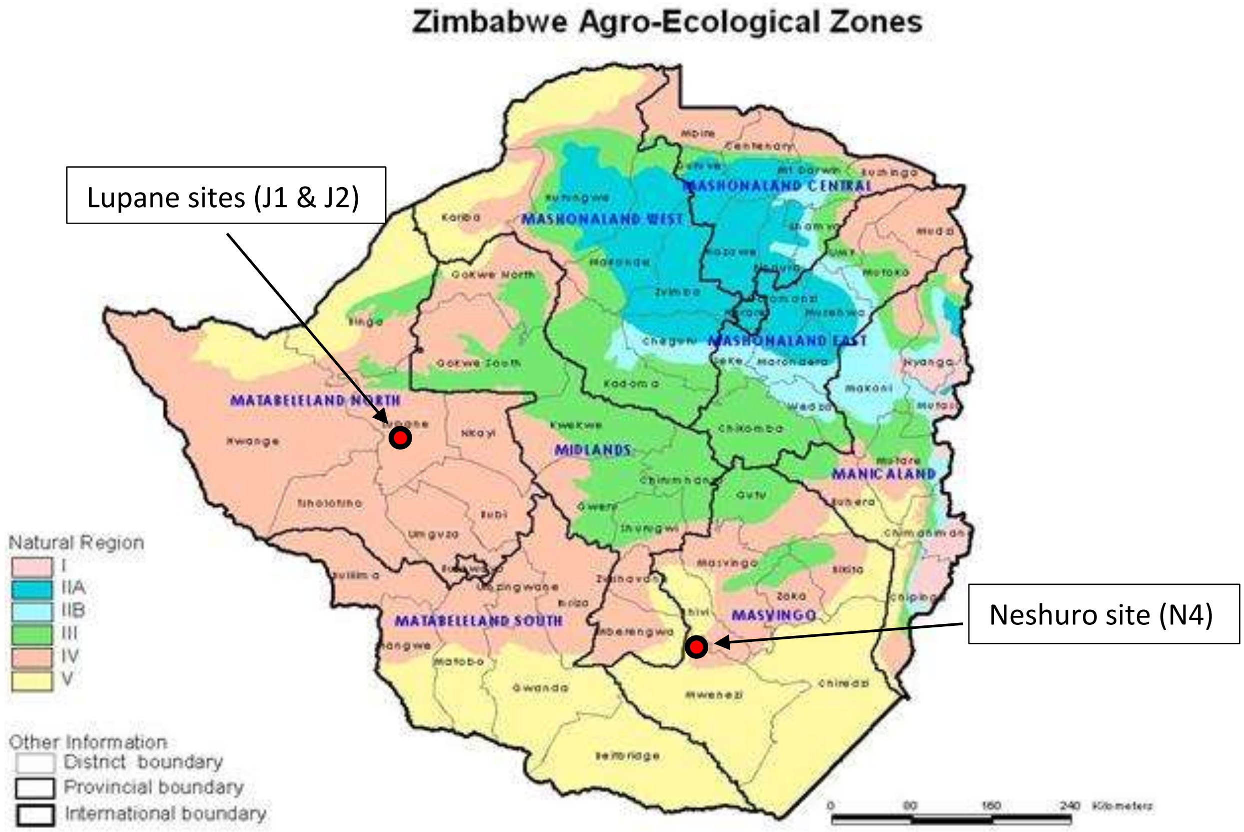

Figure 1. Zimbabwe Agro-Ecological Zones.
Source: http://www.fao.org.

growing (and providing additional biomass to the system) at the end of the experimental period. A final sampling of both lablab and pigeon pea growth was collected in July 2016, but as funds for the experiment had ended, these samples were not dried. To use these final results, a wet weight to dry weight ratio of 4:1 was assumed, which was the average of the lablab wet to dry weight ratios in the experiment. For the pigeon pea and lablab biomass samples that were not dried, the following equation was used to calculate dry weight:

Dry weight = [total wet weight] × 0.25

The lablab and pigeon pea varieties used were both longer-season varieties, and the grain did not mature at sites J1 and J2 before funding for the experiment was over. Cow pea yields were collected for all sites, and are the focus of an economic analysis in a follow up paper (Salomons et al., 2018).

Data analysis

Each data set was analyzed using the PROC Mixed procedure with the Statistical Analysis Software version 9.4 of the SAS System for Windows copyright 2013, considering treatments as fixed effects and replications as random effects. Normality distribution assumptions were tested using Shapiro-Wilks with PROC Univariate procedure and first tested for homogeneity of variance using Bartlett's test. Differences among treatments were tested using the protected least significant difference (LSD) test and considered statistically significant at p <0.05.

RESULTS AND DISCUSSION

Weather data

Precipitation and temperature data were not collected at the experimental sites themselves. Zimbabwe has few active weather stations, so the nearest reliable data to the plots were located at the Hwange Airport (~ 160 km NW of sites J1 and J2) and Chiredze/Buffalo Range located ~ 85 km east of site N4.

In Hwange, 585 mm of rain distributed over 122 days was received over the course of the experimental period (November 2015 to May 2016)[1]. The average rainfall for the Hwange weather station from 2000 - 2015 was 631.5 mm (Mazvimavi et al., 2017). Local staff noted several heat waves during the experimental period.

In Chiredze/Buffalo Range, 360 mm of rain distributed over 95 days was received over the course of the experiment (November 2015 to May 2016)[2]. Masvingo weather station, located approximately 100 km from the

[1]https://www.worldweatheronline.com/hwange-weather-averages/matabeleland-south/zw.aspx
[2]https://www.worldweatheronline.com/chiredzi-weather/matabeleland-south/zw.aspx

Table 1. Treatment means (n=2) and analysis of variance (ANOVA) for selected agronomic parameters from study sites in Zimbabwe. Numbers in columns followed by different letters are significantly different at P<0.05.

	Maize biomass (kg ha^{-1})	Maize grain (kg ha^{-1})	Intercrop biomass (kg ha^{-1})	Intercrop grain (kg ha^{-1})	Total biomass (kg ha^{-1})
Lablab (mulched)	13,629^{a}	5,636^{a}	4,576^{a}	941^{b}	18,206^{a}
Cowpea (mulched)	14,076^{a}	6,199^{a}	2,552^{b}	1,453^{a}	16,628^{ab}
Pigeon pea (mulched)	15,176^{a}	5,749^{a}	838^{c}	30c	16,013^{ab}
Maize only (mulched)	14,196^{a}	5,908^{a}	-	-	14,196^{b}
Lablab (un-mulched)	11,606^{a}	4,224^{a}	3,725^{a}	948^{a}	15,331^{a}
Cowpea (un-mulched)	9,960^{a}	5,041^{a}	2,404^{b}	1202^{a}	12,364^{a}
Pigeon pea (un-mulched)	10,193^{a}	4,208^{a}	617^{c}	163^{b}	10,810^{a}
Maize only (un-mulched)	10,453^{a}	3,986^{a}	-	-	10,453^{a}
Source of variation					
Site (mulched)	<0.0001	<0.0001	0.0053	<.0001	<.0001
Trt (mulched)	0.3542	0.5892	<.0001	<.0001	0.0054
Site-Trt (mulched)	0.0103	0.0163	0.0034	<.0001	0.0220
Site (un-mulched)	0.3038	0.3061	0.0001	<.0001	0.9077
Trt (un-mulched)	0.7543	0.5102	<.0001	0.0006	0.0639
Site-Trt (un-mulched)	0.5755	0.9166	0.0010	0.0017	0.5691

plots at Neshuro, received 500 mm of rain in 2015; the 15 year average for that weather station was 693.7 mm (Mazvimavi et al., 2017).

This data correlates well with harvest and food insecurity reports from June/July 2016. The Famine Early Warning Systems Network (FEWSNET), for example, found that the area surrounding sites J1 and J2 was in Integrated Phase Classification[3] (IPC) 2 (stressed) in terms of food security in June of 2016, while the area surrounding site N4 was in the more serious IPC phase 3 (crisis) phase (FEWSNET, 2017). This data also correlates well with the Zimbabwe Vulnerability Assessment Committee (ZimVac) report from July 2016[4], which found that in the area surrounding sites J1 and J2, maize production from the 2015-16 cropping season was estimated at levels ranging from 35-50% of the five-year average, and that poor households were mainly stressed (IPC Phase 2). Households in the area surrounding site N4, on the other hand, had none or very few crops to harvest due to the erratic and late start of the rains, below-average cropped area, and long dry spells.

Crop production

A summary of results for the mulched and un-mulched treatments are given in Table 1. Because of the significant site, treatment and site by treatment interactions encountered in the combined site analysis (data not shown), data was analyzed separately for all three sites.

Total maize grain production for individual sites is given in Figure 2. Average grain maize yields across all treatments were highest at site J1 and lowest at site N4. The average yield for each treatment at all three sites was much higher than average yields of Zimbabwean farmers in general, despite it being perceived as a drought year by the farmers involved. While any comparisons with national averages are perfunctory at best, these results do give a rough sense of the potential of the general system that was used by the farmers for all treatments: precision planting based on recommended maize spacing; micro-fertilization with composted cattle manure placed close to the growing-maize plant; minimal soil disturbance; and timely and thorough weeding.

The addition of mulch increased maize yields across all treatments at sites J1 (7,449 kg/ha mulched as compared to 4,954 kg un-mulched) and J2 (6,250 kg/ha mulched as compared to 4,060 kg/ha un-mulched) but had minimal impact at site N4 (3,920 kg/ha mulched as compared to 4,080 kg/ha un-mulched). While in general, maize yields were greatest where growing conditions were wettest, this seems at odds with the finding that the addition of mulch increased maize grain yield significantly at sites J1 and J2 (where conditions were wetter and slightly cooler) but had no overall impact on yield at site N4 where conditions were drier and slightly hotter. This may be related to the different soil types at the two sites: sites J1

[3]The IPC is an internationally recognized standard for measuring acute food insecurity, and ranges from 1 (minimal food insecurity) to 5 (famine). For more information see: http://www.fews.net/IPC

[4]http://reliefweb.int/sites/reliefweb.int/files/resources/zimvac_2016_rural_livelihoods_assessment.pdf

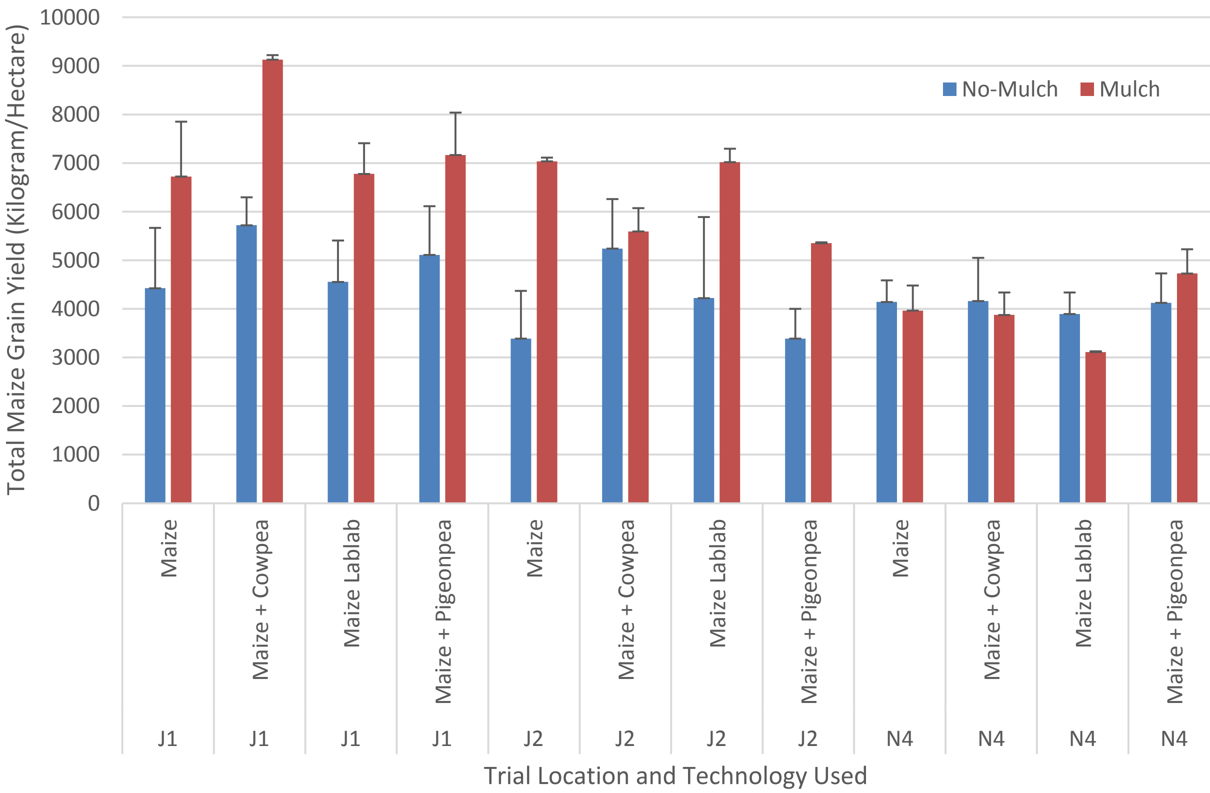

Figure 2. Total maize grain production from various treatments and locations. Error bars indicate standard error for each treatment.

and J2 being on sandy, relatively unfertile soil and site N4 being on a sandy loam of high agricultural potential. The farmer at N4 added supplemental water to keep maize plants alive, and this may explain the lack of difference between the mulched and un-mulched plots.

There were no clear differences in the impacts of the three different legumes on maize grain yields. While some of the legume treatment sites had higher maize grain yields than other legume treatment sites (notably cowpea at site J1 and lablab at site J2), this was not consistent across the different sites. These variable responses were likely due to differences between the sites in terms of farmer practice: the farmer at site J1, for example, planted all three legumes crops 40 days after his maize was planted, while the farmer at site J2 planted her legume crops at the same time as her maize (in both cases, the pigeon peas needed to be replanted as the initial plantings did not germinate). At site N4, the maize and the legume crops were all planted at the same time, but the maize in the un-mulched plots needed to be replanted several times, and by the time that maize had come up the lablab in the intercropped, un-mulched treatments needed to be pruned not to overly compete with the maize. The local research technician noted that the pigeon pea seeds distributed to farmers at all sites had low germination rates, and final density of pigeon pea plants was lower than the density of cowpea and lablab in the respective treatments.

In order to answer the question of whether an intercropped legume can increase maize yield without adding additional mulch in semi-arid areas of Zimbabwe, there were contrasts on a site by site basis of maize grain yields between the mulched, mono-cropped maize plots and the un-mulched, intercropped maize plots. There was a significant difference between these treatments for both sites J1 and J2. Site J1 had an overall estimated maize grain yield increase of 1,593 kg/ha ($P=0.007$) for the mulched, mono-cropped maize treatment as compared to the un-mulched, intercropped treatment. Similarly, Site J2 had an overall estimated maize grain yield increase of 2,753 kg/ha ($P=0.0235$) for the mulched, mono-cropped maize treatment as compared to the un-mulched, intercropped treatment.

Based on these results from sites J1 and J2, the hypothesis that adding a legume intercrop will eliminate the need to add supplemental mulch for increased maize (*Zea mays*) yield was rejected. For site N4, however, there was no significant difference between the maize grain yields from the mulched, mono-cropped plots and the un-mulched, intercropped plots. This was surprising given that this was the hotter, drier, site. In addition, even the un-mulched, mono-cropped maize plots from site N4

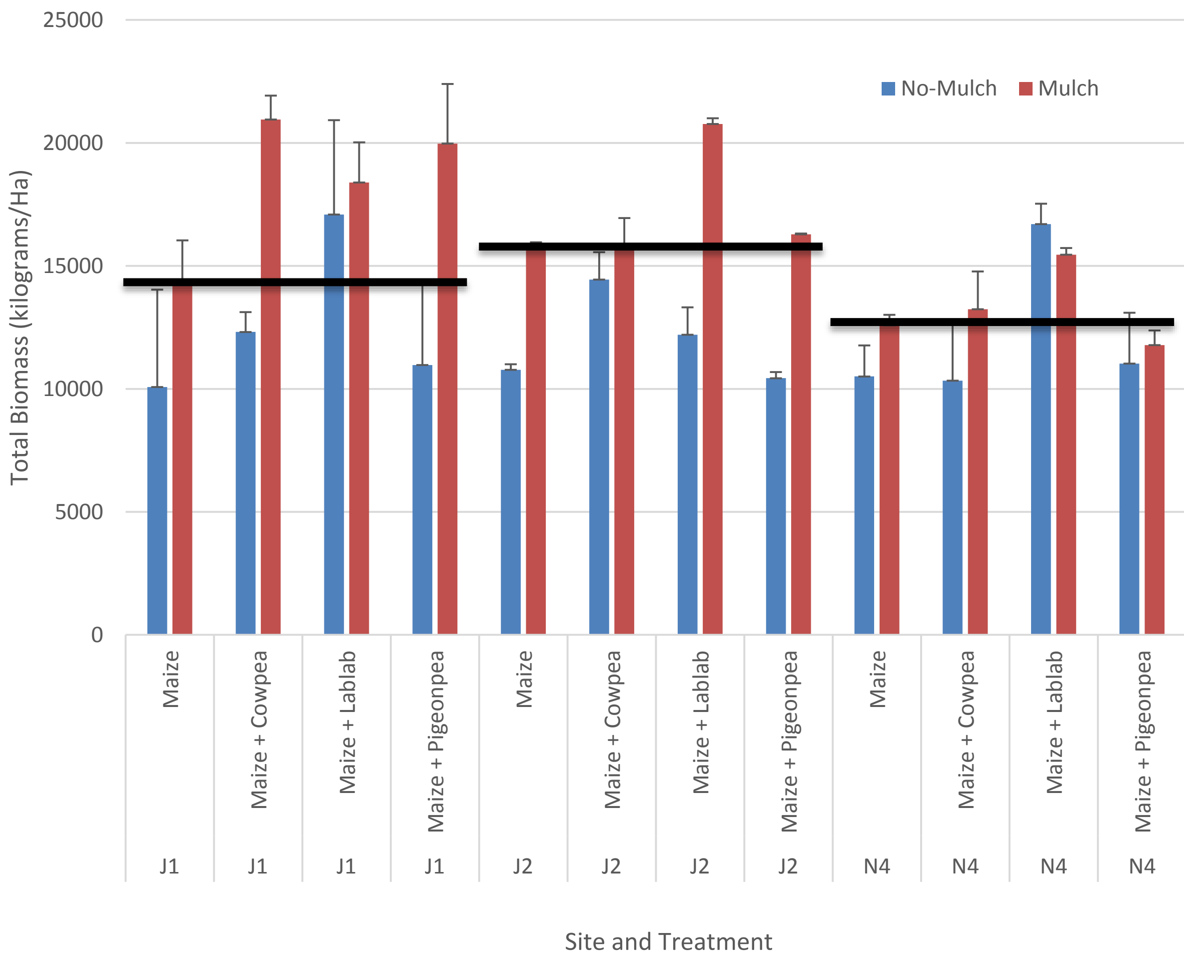

Figure 3. Total biomass production at sites J1, J2, and N4. Error bars indicate standard error for the treatments (n=2). Solid horizontal lines show total biomass production from the mulched, mono-cropped maize for the three sites.

averaged over 4,000 kg/ha in a year when there were widespread crop failures in the surrounding areas. Supplemental irrigation at N4 may explain good yields in the un-mulched plots.

Total biomass production

A second objective was to determine if adding an intercrop to a CA system has the potential to increase the total amount of biomass produced, thereby potentially reducing the need for added mulch for soil cover. Total biomass production (maize biomass plus intercrop biomass) is shown in Figure 3.

For site J1, there was a 5,043 kg/ha (p=0.014) increase in total biomass production when an intercrop was added to the standard, mulched mono-cropped CA maize crop. All three intercrop legumes contributed to the greater total biomass at J1 (Figure 3). At site J2, while there was a 1,843 kg/ha (p=0.049) increase in total biomass production, the biomass increase was almost exclusively due to lablab (Figure 3). No significant difference in total biomass production from adding a legume intercrop was observed at site N4, though once again lablab provided a small boost to biomass production.

The proportion of biomass from maize versus the legume is given in Table 2. Cowpea and lablab biomass represented less than 25% of total aboveground biomass at J1 and J2. However, at the dryer N4 site, the proportion of biomass attributed to the legume was 27 and 45% for mulched and un-mulched cowpea and 82 and 73% for mulched and un-mulched lablab (Table 2). A higher proportion of legume growth at N4 was attributed to greater drought tolerance of the legumes, especially lablab, as compared to maize.

In contrast to cowpea and lablab, pigeon pea contributed a negligible amount in terms of total biomass of the plots. This is surprizing given that pigeon pea is a very common and profitable intercrop species with maize in other parts of Africa (Senkoro et al., 2017) and that pigeon pea has been identified by some researchers as a recommended intercrop with maize under CA systems

Table 2. Ratio of intercrop biomass to maize biomass at experimental sites at time of maize harvest.

Site	Mulch	Cowpea : Maize biomass ratio (%)	Lablab : Maize biomass ratio (%)	Pigeon pea : Maize biomass ratio (%)
J1	Yes	9	11	2
J1	No	13	9	0
J2	Yes	25	25	0
J2	No	24	23	0
N4	Yes	27	82	4
N4	No	45	73	8

(Ngwira et al., 2012; Rusinamhodzi et al., 2017). An explanation for poor pigeon pea performance in the present study was attributed to low germination and slow growth under the maize in this experiment (field notes by research technicians). Traditional varieties of pigeon pea such as used in this experiment generally take much longer to mature than maize, and by the end of this experiment the pigeon peas just began to form green pods.

The greatest increase in biomass production from intercropping was observed at site J1. In the mulched treatments, total maize and intercrop biomass was 21.0 tons/ha for maize/cowpea, 17.4 tons/ha for maize/lablab and 19.5 tons/ha for maize/pigeon pea (Figure 3). One explanation for the impressive total biomass production was the planting pattern of maize and intercrops. The intercrops were planted 40 days after the maize crop, allowing time for maize to become established. Mpangane et al. (2004) observed that highly competitive legumes such as lablab can compete with maize crop production if planted at the same time; they recommended delaying lablab planting by 4 weeks after maize planting. Where lablab was planted at the same time as the maize (N4), the increase in biomass due to lablab was at the expense of maize biomass production (Table 2).

It is important to note that the lablab and pigeon peas will probably continue to grow and add additional biomass long into the dry season. This was corroborated by a report from the field technician at site J1 that there was a severe frost on June 22 that completely destroyed the lablab, however a month later, the lablab was re-growing and flowering while the pigeon pea was not affected by the frost. However, the potential of lablab and pigeon pea to continue growing well into the dry season needs to be tempered by the realization that it is difficult to protect these crops from free grazing livestock in the dry season.

Conclusions

This farmer-managed study showed that additions of mulch and inclusion of grain legumes in maize-based CA had the potential to increase maize yield at most locations. Among legume intercrops, cowpea provided the largest maize yield increase. However, maize yields were increased more by adding mulch than by legume intercrops in the absence of mulch. The implication here is that to increase maize yield, some sort of mulch was necessary, and intercrops alone were not an adequate substitute for this mulch. Therefore, farmers should continue to seek opportunities to ensure fields have some level of surface cover. Future research should seek to understand the optimum level of mulch required, especially after many years of CA when soil organic matter levels, and hence water holding capacity, may have increased. Such work may benefit from long-term controlled studies located in different agroecozones.

Adding a legume intercrop increased the total amount of biomass production, thereby reducing the amount of mulch required for surface cover. This means less labour for mulch collection. The greatest positive effect of intercropping on biomass production occurred where rainfall was higher and where the legume planting was delayed 40 days after maize planting. These results demonstrate the importance of site, including farmer management, in the success of intercropped based CA smallholder systems. This observation points to the importance of extension to train farmers on optimum intercropping planting regimes.

Farmer participation was critical to conducting these studies in the context of small-holders in Zimbabwe. Farmers in this study viewed their plots as their classrooms, and will continue to experiment on their own after the project. In the present study, only 3 of 8 sites were deemed appropriate for reporting (5 additional sites were conducted but problems were encountered). Greater involvement of research and extension workers in these on-farm studies will improve their success rate.

CONFLICT OF INTERESTS

The authors have not declared any conflict of interests.

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