FARMER MANAGED RESEARCH TO ASSESS LEGUME INTERCROPPING IN CONSERVATION AGRICULTURE SYSTEMS IN RURAL ZIMBABWE

BY

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A Thesis
Submitted to the Faculty of Graduate Studies of
The University of Manitoba
in partial fulfilment of the degree of

MASTER OF SCIENCE

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ACKNOWLEDGEMENTS

To Dr. Martin Entz and his team for their invaluable assistance in planning, conducting, and analyzing the work leading to this thesis;

To the office staff at the Department of Plant Sciences for their help with the practicalities of the thesis process;

And finally to Maguy, Lucas and Caleb – for giving me the time and space needed to work on and complete this thesis;

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ABSTRACT

Salomons, MJ. M.Sc. The University of Manitoba, June 2018. Farmer Managed Research to Assess Legume Intercropping in Conservation Agriculture Systems in Rural Zimbabwe. Major Professor: Martin N. Entz

The lack of adequate mulch and crop rotations are major constraints to the implementation of conservation agriculture (CA) for smallholder farmers in sub-Saharan Africa. One possible solution to these constraints is intercropping the main cereal crop with a leguminous cover crop; a technology option that also has the potential to improve the food security and economic productivity of smallholder CA systems. This study used farmer managed research plots to assess the impacts of integrating different grain legumes (cowpeas (*Vigna unguiculata*), lablab (*Lablab purpureus*), and pigeon pea (*Cajanus cajan*) into maize based CA farming systems in two semi-arid regions of Zimbabwe. The results from one cropping cycle (late 2015 to mid-2016) found that while there was a significant increase in total biomass production when an intercrop was added to the standard, mulched, monocropped CA maize crop at one site, there was no difference at the second (drier) site and that the addition of a legume intercrop reduced, but did not eliminate the need to add supplemental mulch to CA based farming systems. However, the addition of the cowpea intercrop in particular significantly increased the economic profitability and food security impacts of the farming system at both sites (an effect that was more pronounced at the drier site). Overall, this study found that intercropping of legumes into CA based systems had the potential to improve sustainability, productivity and profitability, resilience and food security impacts for the farmers involved in this study.

1. INTRODUCTION

A farming system needs to provide for the well-being of farmers. Furthermore, this well-being should be:

- *sustainable* – meeting basic needs while allowing the earth system to operate within planetary boundaries (Rockström et al. 2017);
- *productive and profitable* - able to provide for the well-being of farmers and the surrounding society, including return on investment (Dogliotti et al. 2014; CARE 2015);
- *equitable* - enabling equal access to opportunities, resources, services and rewards for all (CARE 2015);
- *resilient* - able to absorb disturbance and reorganize while undergoing change so as to retain essentially the same function, structure, identity, and feedbacks (Walker et al. 2004).

Farming systems in sub-Saharan Africa are dominated by small-holder farmers and rain-fed basic grains production. Rainfall patterns across the continent are increasingly poorly distributed with severe dry spells (Sennhenn et al. 2017). Current production systems coupled with high rates of population increase have led to an accelerated loss of soil fertility, with the total extent of severely degraded soils due to agricultural activities estimated at over 1 million km^2 (Vagen et al. 2005). Poor soil fertility and nutrient availability are widely acknowledged as the major biophysical limitations to agricultural production in the continent (Vanlauwe and Giller 2006; Tittonell and Giller 2013). Mineral fertilizer remains a scarce, expensive and risky resource for most smallholder farmers, with typical prices 3-5 times higher than in Europe due to lack of infrastructure and production facilities (Thierfelder et al. 2015a). An analysis of 13,000 farms across 17 sub-Saharan Africa countries found that almost 40% of farming households were unable to achieve even basic food self-sufficiency (Frelat et al. 2016).

Conservation Agriculture (CA) – based on the three interlinking principles of minimum soil tillage, permanent soil cover, and crop rotations and/or associations – is increasingly gaining prominence as part of the solution to these challenges. Researchers, development organizations and governments have promoted CA in Africa extensively for at least the last two decades, and a growing number of farmers across Africa are using CA production methods. Where CA is most needed, however – semi-arid areas that suffer from high and increasingly erratic climatic variability – CA is the most difficult to implement due in part to shortages of biomass for soil cover. High degradation rates from temperatures and termites, and high competing needs from livestock and other domestic uses lead to a situation where at certain times of the year crop residues can fetch a higher price than the grain it produced (Lahmar et al. 2012).

Intercropping of the main crop (typically maize (*Zea mays* L.)), although other cereal crops are also grown) with a leguminous intercrop has been suggested as one partial solution to these challenges. This thesis - based on the results of farmer experiments from one cropping cycle of CA maize intercropped with grain legumes – is intended to gather preliminary evidence for four main questions:

Question	Hypothesis	Data to Test
Can adding a legume intercrop eliminate (or at least reduce) the need to add supplemental mulch?	Adding a legume intercrop to a CA field will eliminate the need to add supplemental mulch and thus improve the sustainability and equitability of the overall farming system	Maize yields under mulched and intercropped trials: (mulch + no mulch) X (monocropped + 3 different intercrops) X (3 farmers at 2 different locations)
Can adding a legume intercrop increase the total amount of biomass produced by this system?	Adding a legume intercrop to a CA field will increase the total amount of biomass produced per unit area and thus improve the sustainability and productivity of the farming system	Total biomass production under mulched and intercropped trials: (mulch + no mulch) X (monocropped + 3 different intercrops) X (3 farmers at 2 different locations)
Can adding a legume intercrop make the farming system more economically productive?	Adding a legume intercrop to a CA field will increase the overall yield / unit area and the simple economic gain from the field	Total yield of maize and cowpea (monocropped + intercropped with cowpea) X (mulched + un-mulched)
Can adding a legume intercrop improve the food security benefits of this farming system?	Adding a legume intercrop to a CA field will improve the overall food security situation of farm families.	Total yield of maize and cowpea (monocropped + intercropped) X (mulched + un-mulched); value of these crops; value of food assistance basket

The thesis is divided into four chapters:

1. A literature review on the major components of this farming system;
2. A summary and conclusions from the evidence gathered on the first two questions (1 & 2) above;

3. A summary and conclusions from the evidence gathered on the last two questions (3 & 4) above
4. A review of the main learnings from this experiment

2. LITERATURE REVIEW

As outlined in the introduction, this study tests the use of a legume-grain intercrop, a traditional practice in many African farming systems. This study, however, tests this intercrop in a new paradigm – a hoe-based conservation agriculture system - where soil-covering mulch is critical. The major component of the study was a replicated field experiment conducted together with farmers on three fields in two semi-arid regions of Zimbabwe. A maize *(Zea mays* L.*)* main crop was grown with and without one of 3 leguminous intercrops: (lablab (*Lablab purpureus* (L). Sweet), pigeon pea (*Cajanus cajan* (L.) Druce), and cowpea (*Vigna unguiculata* (L.) Walp)), using current farmer practice and conservation agriculture principles. The following literature review is focused on the main elements of this farming system.

2.1 Conservation Agriculture

Tillage – the mechanical manipulation of soil to manage weeds, incorporate crop residues and prepare a uniform surface for planting – has been an integral part of many agricultural systems around the world for thousands of years. While Canadian farmers and researchers began experimenting with crop agriculture without tillage in the late 1890s (Janzen 2001), the essential role of tillage began to be more seriously questioned (at least among Western farmers) starting in the 1930's when dustbowls devastated large areas of North America (Farooq and Siddique 2015). The concept of protecting the soil by reducing tillage and keeping the soil covered began to slowly grow in popularity, and became known by various terms such as conservation tillage, minimum-tillage, and no-tillage (Friedrich et al. 2012). The term Conservation Agriculture (CA) is now more generally used, and specifically refers to a farming system based on three interlinking principles (Kassam and Friedrich 2012; FAO 2017a):

- Continuous minimum mechanical soil disturbance - no or minimum mechanical soil disturbance, including seeding or planting directly into undisturbed or untilled soil;
- Permanent organic soil cover - enhancing and maintaining organic mulch cover on the soil surface, using crop residues, cover crops or imported organic matter;
- Diversification of crop species - both annuals and perennials and including trees, shrubs, pastures and crops grown in sequences and/or associations and/or rotations.

For large scale farmers who rely on mechanized agriculture (and often the use of herbicides) CA can offer huge advantages: increasing the efficiency of land, energy, water, and nutrient use and minimizing soil erosion (Andresson and Giller 2012). Over the last few decades CA has been adopted on a massive scale on large-scale farms in North and South America, Australia, South Asia and South Africa (Kassam et al. 2015); and on smaller farms in South America thanks in part to the development of animal-drawn zero-till planters (Bolliger et al. 2006). If adoption by farmers is one of the acid tests of an agricultural technology, CA - globally speaking - is a resounding success.

Researchers and farmers have experimented with CA in Africa for at least fifty years (Kannegieter 1967; Lal 1974; Smith 1988). In the last two decades CA has been heavily promoted (particularly in southern Africa) as a strategy to improve food security and reverse soil degradation in the face of climate change (Giller et al. 2009; Mafongoya et al. 2016). Regardless, adoption by smallholder farmers in Africa has been minimal: less than 1% of cropland in Africa is currently planted under CA (Kassam et al. 2015).

Despite the slow uptake, studies on the impacts of CA in sub-Saharan Africa are generally positive. While global meta-analyses on the effects of CA on agricultural yields are inconclusive and sometimes controversial (c.f. Brouder and Gomez-

Figure 2.1: Jane Wajicko, from Murang'a County, Kenya in her conservation agriculture field (Source: CFGB)

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. 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). Meta-analyses of CA studies from across southern Africa show that while localized areas of yield reduction do exist, CA on average does provide an increase in yields (Thierfelder et al. 2015b), however these results can take time (usually 2-5 years) especially in more favorable agro-ecological environments (Thierfelder et al. 2017). Some researchers and organizations point to an average yield gain of 20% for CA in sub-Saharan Africa when comparing like to like, but comparing worst conventional practice to best CA practice (which is often the case) then increases of 225% are common (Rusinamhodzi 2017). For example, a survey of small-holder farmers in Zimbabwe (Woodring and Braul 2011) found that small-scale, hoe-based CA that also incorporated practices such as early seeding, crop fertilization and proper plant spacing increased maize yields by 100 to 400%. Blank (2013) reported that even Zimbabwe farmers who plow for cultural reasons often have a small plot of CA to ensure a food supply for the household. Social-economic benefits of CA are thought to be particularly important for women (Woodring and Braul 2011; Blank 2013).

Unfortunately, where CA is most beneficial in terms of agricultural production in Africa (semi-arid areas), it is the most difficult to implement. The organic mulch cover in CA fields increases soil water evaporation control, soil water infiltration, soil water runoff control and soil loss control (which are all critical in most semi-arid areas of Africa) but to achieve these benefits, crop residue levels of between 2 and 8 tons ha^{-1} $year^{-1}$ are required (Ranaivoson et al. 2017). Rusinamhodzi (2017) has estimated that to achieve these benefits three tons of cereal or grain production per hectare is the minimum needed (without adding supplemental mulch) but this is more than current average production levels in Africa. (This low average production is due in part to the inherently poor soil fertility prevalent in smallholder farming across Africa (Giller et al. 2011a)).

For resource-constrained smallholders without access to herbicides, CA can also lead to increased time and labour requirements, either for weeding or to add supplemental mulch to reduce weeds (Lee and Thierfelder 2017). While yields and profits are higher under CA, this requirement to add additional mulch is part of the reason labor demand is also increased and may be the constraining factor for CA adoption by smallholder farmers in southern Africa (Nyamangara et al. 2014). Comparatively higher levels of livestock diversification across Africa also tend to increase competition for the use of crop residues for livestock – another major constraint to implementation of CA by African smallholder farmers (Thierfelder et al. 2015c).

While research on the impact of crop residues on nitrogen dynamics in soils is inconclusive (Verhulst et al. 2010), some researchers believe CA can result in nitrogen immobilization, particularly in areas of low quality crop residues (Droppelmann et al. 2017). This may be one of the reasons production under CA systems in the infertile, sandy soils which predominate in semi-arid regions of southern Africa can be constrained for farmers without access to sufficient manure or mineral fertilizers (Vanlauwe et al. 2014; Masvayaa et al. 2017).

2.2 Intercropping

Intercropping involves growing two or more crop species or genotypes together and which coexist for a time (Brooker et al. 2015). Intercropping has traditionally and almost universally been used by smallholders in the tropics, including through most of Africa (Leakey 1936; IDRC 1976; Vandermeer 1989; Mafongoya et al. 2003).

While intensive cropping systems based on the cultivation of monocrops have more recently been preferred throughout much of the world (Gaba et al. 2015), intercropping remains common in countries with high amounts of subsistence agriculture and low amounts of agricultural mechanization, usually undertaken by farmers practising low-input, low-yield farming on small parcels of land (Ngwira et al. 2012b). Traditional intercropping systems in Africa – which continue to be practiced in many of the more remote areas – range from polycultures of annual and perennial species grown in the midst of forested areas to growing a variety of legume and vegetable plants scattered through a main cereal crop. Most intercropping systems, however, involve growing a cereal crop together with a legume crop (Hauggaard-Nielsen and Jensen 2005). For example, on a typical farm in the highlands of western Kenya, maize intercropped with beans (*Phaseolus spp.* L.) represents the major cropping system, occupying c. 75% of the area of smallholder farms (Tittonell 2007). While these types of intercropping systems have long been recognized as a rational strategy both in terms of profit maximization and risk minimization (Norman 1974), most research and extension efforts within Africa have focused on temperate style (and more industrially applicable) monocropping. However, there is a growing interest in higher levels of research into and promotion of legumes in Africa's farming systems to address the dual problems of resource degradation and increasing vulnerability (Snapp 2017), as including N_2 fixing plants (legumes) within agricultural fields can provide better

Figure 2.2: Intercropping of maize and lablab bean (source: ACT)

control of soil erosion, reduced water losses, reduced nutrient losses, and increased nutrient inputs (Giller 2001). Including these legumes as an intercrop instead of as a monocrop in rotation has a number of potential impacts for smallholder farmers, which are outlined below.

2.2.1 Sustainability Impacts of Intercropping

Intercropping has several potential soil improving benefits. Studies from West Africa (Zougmore 2000) and Eastern Africa (Kariaga 2004) have found that growing a legume together with a main cereal crop can reduce soil loss and runoff. Intercropping with velvet bean (*Mucuna pruriens* (L.) DC.*)* compared to traditionally fertilized monocropped maize has been found to result in higher macrofaunal density and biomass (Blanchart et al. 2006). The increased overall biomass production that often results from the addition of an intercrop can lead to increased water infiltration (from the creation of a larger number of root channels) and additional organic input may increase the soil C content in the long-term (Six et al. 2002; Corbeels et al. 2006; Stewart et al. 2007; Ngwira et al. 2012b; Rusinamhodzi et al. 2012). This is particularly important in coarse-textured soils such as those prevalent across much of southern Africa, as sandy soils offer little structural (aggregate) protection (Chivenge et al. 2007).

The potential benefits of intercrops on pest populations have been known for some time (IDRC 1976). Gaba, Lescourret et al. (2015) review a number of ways that intercrops reduce pest populations in farmers fields, such as resource dilution, habitat fragmentation, and allelopathic effects. One meta-analysis (of 26 studies) of the effects of intercropping found beneficial effects on biocontrol of herbivorous pests consistent across geographical regions and by type of primary crop (Iverson et al. 2014); a similar meta-analysis (of 50 studies) also found beneficial effects on pest control, but which was dependent on the intercrop, primary crop, as well as the country of the study (Lopes et al. 2016). Some studies in sub-Saharan Africa have found beneficial impacts of

Figure 2.3 Cowpea intercropped with Sorghum (*Sorghum bicolor* (L.) Moench). Source: CFGB

intercropping on pest populations. For example a Ugandan study found reductions in termite attacks and increases in the nesting of beneficial predatory ants in intercropped maize fields (Sekamatte et al. 2003). The 'push-pull' system developed by ICIPE in Kenya (intercropping maize with a pest-repelling legume and planting a trap crop around the border of the plot) has been found to be successful in controlling cereal stem borers (Khan et al. 2011). Anecdotal evidence from farmers in the Foodgrains Bank network from across Africa have mentioned that maize intercropped with legume species suffers less damage from maize pests such as the Fall Army Worm (*Spodoptera frugiperda* J.E. Smith), and that lablab intercropped with maize suffers from less pest damage than monocropped lablab.

Intercropping with legumes has also been shown to reduce the risk of total harvest losses due to parasitic witchweed (*Striga hermonthica* (Delile) Benth.) (Khan et al. 2008; Thierfelder et al. 2013). This is possibly due to legume-induced suicidal germination of striga seeds (Midega et al. 2018).

2.2.2 Productivity and Profitability Impacts of Intercropping

Intercrops have been shown to increase nutrient availability to the primary crop, thereby increasing crop yields and/or reducing the amount of required agricultural inputs. For example, the cultivation of legumes in smallholder farming systems as an intercrop has the potential to increase nitrogen (N) availability in the soil through biological N_2-fixation (Giller 2001). Even in cases where most of the fixed N_2 is removed at crop harvest, more N may be available for subsequent crops due to an N-sparing effect (the absence of soil N depletion compared with a cereal grown without sufficient N input) or reduced N immobilisation of soil N due to the lower C-to-N ratio of legume residues (Chen et al. 2014). While cereals may benefit from legume-fixed N, cereal crops may also increase Fe and Zn bioavailability to the companion legumes (Xue et al. 2016). Intercropping of a legume with maize has also been shown to increase P availability under low phosphorous conditions (Latati et al. 2016).

Researchers looking at increasing agricultural productivity within Africa point out that intercropping can enhance the efficiency of land use by more complete and complementary utilisation of nutrients, water and solar radiation (Giller et al. 1997; Li et al. 2014), and there is good evidence from across Africa that this can result in increased yields and/or increased profitability for smallholder farmers. A study from Malawi found that maize legume intercrops significantly raised maize grain yields (between 0.5 and 3.4 t ha^{-1}) when compared with sole crop unfertilized maize (Kamanga et al. 2009). In a study from the Sahel, the grain yield of intercropped sorghum-cowpea was double that obtained with sorghum or cowpea monocultures (Zougmore 2000). A 7 year research study in Kenya found that a maize-pigeon pea intercrop produced 24% higher maize yields than either sequential or rotational maize-legume systems (Rao and Mathuva 2000), while another study from Kenya found that intercropping maize and lablab improved land productivity giving land equivalency ratios of between 1.0 and

1.5 (Gitari et al. 2011). In Zimbabwe, intercropping legumes with maize was found to help maintain maize yield when maize was grown without fertilizer on sandy soils, although this same study found annual margins were higher for both fertilized sole maize (69% higher) and unfertilized sole maize (25% higher) than fertilized and unfertilized intercropped maize (Waddington et al. 2007). These results may have been an anomaly due in part to unique market conditions existing in Zimbabwe at the time (Rusinamhodzi et al. 2012), which would make sense given the many other studies which have found that intercropping is economically advantageous for smallholder farmers. For example, a study in Northern Ghana of various maize-legume intercrops found that while sole crops produced higher yields, economic profitability and land equivalency ratios were significantly higher for intercrops than for either sole crop (Kermah et al. 2017). Similarly, intercropped cowpea and maize was found to offer a 33.6% higher monetary return over monocropped maize in Tanzania (Fischer 1976), and a study from

Figure 2.4: Intercropped maize & pigeon pea, Kenya (source: CFGB)

Mozambique found intercropping maize and pigeon pea to be profitable with a rate of return of at least 343% over sole maize cropping (Rusinamhodzi et al. 2012).

In addition to potential yield and economic benefits, residues from intercropping can provide valuable fodder for ruminant livestock (Tarawali et al. 2002). A study from Brazil found intercropping with pigeon pea produced more than double the amount of plant biomass compared to sole maize, and had the potential to produce enough plant biomass for the purposes of both mulching and for producing a substantial protein-rich fodder (Baldé et al. 2011). A study from Uganda found that a maize:lablab intercropping system produced 4.4 tons ha^{-1} $year^{-1}$ more biomass than a maize monocrop, with 8.4% higher crude protein levels as well as increased calcium and phosphorous levels (Kabirizia et al. 2007).

While intercropping does entail some extra labour for planting, some advocates of intercropping claim that it reduces the amount of weeding and thus is a net labour savings technology. A review of studies from across Africa largely supports this claim, with the caveat that this is dependent on crop species used, rainfall, and prevalent weed species (Lee and Thierfelder 2017).

2.2.3 Impacts of Intercropping on Equality

Forty years ago (Jodha 1979) pointed out that any break-through in intercropping technology will benefit less-endowed farmers more than better-endowed farmers, and thus offers a unique opportunity of explicitly incorporating equality considerations in agricultural research strategies. More recently, Lithourgidis, Dordas et al. (2011) concluded that while intensive monocropping is easier for large-scale farmers, intercropping may be a better way of ensuring livelihoods for small-scale farmers who do not have ready access to machinery, agricultural inputs or markets. For resource constrained households with small landholdings, intercrops have several advantages. They generally do not reduce the household's supply of their staple (usually cereal) crop; because they fix nitrogen, they are suitable for marginal land; they yield well without inorganic fertilizer; and, as they are usually cultivated by women, income from these crops is often controlled by women (Orr 2001). Intercrops require little or no additional labour for weeding, and in fact some studies have found intercropping can have weed suppression effects, which can also help minimize labour requirements at peak seasons – a task that commonly falls to women (Chikoye et al. 2001; Sekamatte et al. 2003). For many farmers in Africa faced with small land holdings and limited purchasing power, intercropping with legumes may be one of the few viable options for improving productivity (Thierfelder et al. 2012b; Leonardo et al. 2015).

2.2.4 Resilience Impacts of Intercropping

Intercrops exhibit greater yield stability and less productivity declines during a drought than monocultures (Vandermeer 1989). The yield of intercropped legumes has been found to increase as stress due to insufficient water increases (Natarjan and Willey 1996) which helps to reduce the risk of reduction or failure of the cereal crop and leads to more stable production (IDRC 1976). Maize-legume intercrops in Malawi were found to not only yield more but were associated with less risk than maize-legume rotations (Kamanga et al. 2009). Meta-analyses have found that intercropping offers greater financial stability than sole cropping, which makes the system particularly suitable for labor-intensive small farms (Lithourgidis et al. 2011).

2.2.5 Food Security Impacts of Intercropping

Numerous studies have found significant improvements to food security from the inclusion of a grain-legume intercrop (Rusinamhodzi et al. 2011; Rusinamhodzi et al. 2012; Makate et al. 2016). Maize-legume intercropping has also been found to have nutritional benefits beyond the legume grain itself. For example, one study in Zimbabwe found the grain N content of a maize crop planted subsequently to an intercropped maize-legume intercrop was improved by 82% relative to the sole maize control (Jeranyama et al. 1997). Leaves of many intercrop species are commonly eaten throughout Africa during the vegetative state. Increasing the complexity of agricultural systems can also contribute to food security in a changing climate through increased resilience (Khumairoh, Groot et al. 2012).

2.2.6 Challenges with Intercrops

While most research has found positive impacts of intercropping for smallholders in sub-Saharan Africa (Sileshi et al. 2008), this is not a universal finding. Certain economic conditions (for example, if the price of cereals is higher than legumes) may encourage smallholder farmers to persist with growing low input sole crop maize (Waddington 2007). Farmers from Zimbabwe and other African countries have pointed out to the author that they have more difficulty marketing excess legume production than excess maize production. Bationo, Waswa et al. (2011) point out that if soil fertility continues to decline across Africa, intercropping will become more and more problematic with regard to increasing crop yields, due to competition for nutrients and water. This will be especially critical in marginal semi-arid zones.

The use of an intercrop can constrain the use of herbicides, and make harvesting of the main crop or intercrop more difficult (although if a good choice of intercrops is made, no herbicides should be needed (Gulden 2018)). In low phosphorous soils, the benefits of intercropping are reduced. Yields of either of the crops in an intercrop can be reduced due to competition, and the yields of shorter crops (i.e. most legumes) are especially prone to yield reduction due to shading effects. Finally, the heavy focus on monocultures and chemically dependent cropping over the last half decade (Gaba et al. 2015) means that comparatively little research has been done on intercrops and their associated challenges (such as row spacing guidelines, availability of legume seeds and appropriate inoculants, advice on fertilizer mixtures, etc.).

2.3 Integrating Conservation Agriculture and Intercropping

While both Conservation Agriculture (CA) and intercropping have been proposed as potential solutions for some of the agricultural challenges facing large parts of Africa, there are relatively few studies which have looked at the integration of both technologies.

Those studies that have focused on the impacts of intercropping on cereal production alone or on legume production alone have tended to be negative about intercropping. For example, Anyanzwa et al. (2010) found that maize intercropped with soybean (*Glycine max* (L.) Merr.) in Kenya had lower yields than either continuous maize or maize rotated with soybeans. Thierfelder et al. (2012b) found that intercropping maize with cowpea in Zimbabwe had a much lower effect on the associated maize yield than full rotations with cowpea. Mupangwa et al. (2012) found that lablab intercropped with maize in Zimbabwe produced less biomass and had lower residual soil fertility than when grown as a sole crop.

Those studies that looked at the impact of intercropping on overall crop production (both the main (usually a cereal) and the intercrop (usually a legume) together) and the impact on the wider farming system, however, have been generally positive about intercropping. So while Ngwira et al. (2012b) concluded that associating maize with legumes such as pigeon pea, mucuna, or lablab in Malawi reduced maize yields compared to monocropped maize, particularly in drier years, they recommended the intercropping of maize and pigeon pea under CA as a win-win scenario for farmers due to overall crop yield improvements and attractive economic returns. Thierfelder et al. (2015a) – based on their study of maize-cowpea intercropping systems in Malawi -

suggested it was more beneficial over time to practice a maize-legume intercrop than to plant sole maize under CA as this provided additional legume yields without significant maize yield penalties. Kimaro et al. (2016) found that including lablab as an intercrop in a maize based CA system significantly increased overall production for farmers in Tanzania. Mupangwa et al. (2017) found that intercropping maize and cowpea in Zambia gave a land equivalency ratio of 2.01 over four seasons compared to full rotations under CA, and likewise Rusinamhodzi et al. (2017) found that intercropping maize and pigeon pea produced significantly higher yields of both crops than in corresponding sole treatments in Tanzania.

The integration of CA and intercropping may also have other beneficial impacts on the farming system. For example, studies in the USA have found that no-tillage and intercropping with cover crops may result in an increased soil moisture holding capacity, and for degraded sandy/coarse soils (such as are common in Zimbabwe) this may result in additional soil moisture holding capacity (Saxton and Rawls 2009).

2.4 Intercropping Species for this Study

2.4.1 Cereal Crop: Maize (Zea mays (L.))

Maize is an annual cereal plant of the grass family (Poaceae). It is commonly believed, but not completely clear, that maize arrived in Africa along with Portuguese sailors around the year 1500 AD (Miracle 1965). What is more clear is that maize is a major staple food crop in sub-Saharan Africa, accounting for 50% to 80% of total calories consumed in many countries, and covering 60% or more of the cropped area in countries such as Malawi, Zimbabwe and Zambia (Sileshi et al. 2008). In some countries in Africa, it is common to find maize intercropped or relay cropped with a legume (Orr 2001). Traditional (land races), open pollinated 'improved' and hybrid varieties of maize are all widely used across Africa, although modern varieties have sometimes been promoted with the provision they are only used as monocrops (Snapp and Fisher 2015).

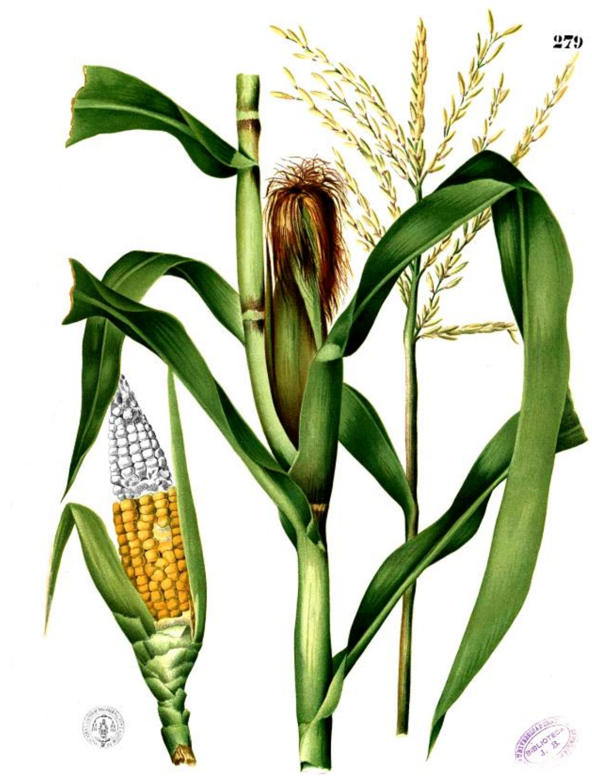

Figure 2.5: Maize (*Zea mays*) (source: wikimedia.org)

In general, maize yields across sub-Saharan Africa remain stubbornly low: the average across sub-Saharan Africa from the period 2007-2016 was 1.9 tons ha^{-1}, although there is significant variation between countries (FAO 2017b). For example, the average yield for Zimbabwe over the same period was only 0.7 tons ha^{-1}.

2.4.2 Legume Crops

The legumes for this study were chosen because 1) they are indigenous to Africa with a long history of use by small-scale farmers, 2) they are multi-purpose (forage, human food – pulse and fresh vegetable, and soil fertility improver), and 3) they have traditionally been grown as intercrops.

2.4.2.1 Cowpea (Vigna unguiculata (L.) Walp.)

Cowpea is a warm-season herbaceous legume. Native to Africa, cowpea is one of the most important food legume crops in Africa. The history of cowpea dates to ancient West African cereal farming, 5 to 6 thousand years ago, where it was closely associated with the cultivation of sorghum (*Sorghum bicolor* (L.) Moench) and pearl millet (*Pennisetum glaucum* (L.) R. Br.) (Davis et al. 2018). It is currently grown as a grain crop for human consumption with over 4 million hectares cultivated worldwide. Cowpea can also be used as a forage crop, or as a vegetable for human consumption (leaves and green pods).

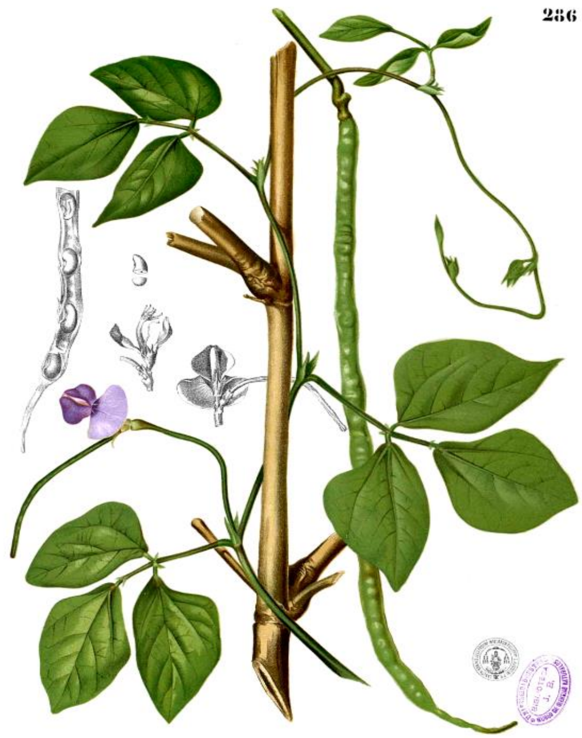

Figure 2.6. Cow pea (*Vigna unguiculata*) (source: wikimedia.org

Worldwide, average cowpea yields are 700-800 kg ha, although it can yield up to 2,500 kg ha under optimal conditions (N2Africa 2015). The average yield across Africa for the period from 2007-2016 was 0.52 tons ha^{-1} (FAO 2017b) (average yields from Zimbabwe for this same period are not available).

The Purdue Alternative Field Crops Manual (Davis et al. 2018) reports that common cowpea plant types are highly variable (spreading, bushy or erect annuals or short-lived perennial shrub), while growth habit ranges from indeterminate to fairly determinate with the non-vining types tending to be more determinate. Cowpea generally is strongly tap-rooted, with root depth measured at up to 2.4 metres 8 weeks after seeding. Short varieties may start flowering only 60 days after planting while the taller woody genotypes flower much later, from 180–250 days after planting. Cowpea is very drought tolerant, and able to grow with a dry season exceeding 6 months and rainfall <300 mm, but does best with 600–1,000 mm annual average rainfall. Cowpea is also very tolerant of hot conditions, and can grow in temperatures >35ºC when soil moisture and fertility are adequate. It can grow at altitude but growth is slowed by low temperature. The N-fixing potential of cowpea is up to 140 kg ha^{-1} residual nitrogen (Cook et al. 2005).

In some parts of Africa (particularly West Africa) intercropping is the main method of growing cowpea, with up to 90% grown in an intercrop with sorghum or millet (Vandermeer 1989; Laberge et al. 2011). Intercropped cowpea can make significant nitrogen contributions to both the intercropped cereal and subsequent cereal crops – a study from the Sahelian region of Africa found that cowpea was able to provide approximately 10% of an intercropped and subsequently planed millet crop's N needs (Laberge et al. 2011). In Nigeria, where 80% of the sorghum and cowpea are grown as intercrops, one study found that intercropping sorghum and cowpea resulted in an 8% higher LER as well as higher profit potential (Oseni 2010); while another study from the same region found that intercropping of cereals and cowpeas resulted in an over 300% increase in productivity, enhanced income generation, and improved livelihoods of farm families (Singh and Ajeigbe 2007). A study from the Sahelian region of Africa found that intercropping cowpea with pearl millet resulted in 50 to 125 % higher total yields (Maman et al. 2017). A similar study in Zimbabwe found that maize yields were not impacted by intercropped cowpea under moderate levels of N fertilization, but that this provided the additional benefit of a cowpea grains as well as reducing the N fertilizer needs of subsequent maize crops (Jeranyama et al. 2000).

2.4.2.2 Lablab (Lablab purpureus (L.) Sweet)

Lablab is a vigorously trailing, twining herbaceous plant. Most domesticated varieties are annuals or short-lived perennials. Lablab is one of the most agro-morphologically diverse and versatile tropical legume species and is used as a pulse (also used as ‘dhal’), vegetable (green bean, pod, leaf), forage/green manure, herbal medicine, ornamental, and even as a pharmaceutical (Cook et al. 2005; Maass et al. 2010).

Lablab is adapted to annual rainfall regimes from 650 to 3,000 mm. It is capable of extracting soil water from at least 2 metres depth even in heavy textured soils. Lablab is drought tolerant when established, but loses leaves during prolonged dry periods.

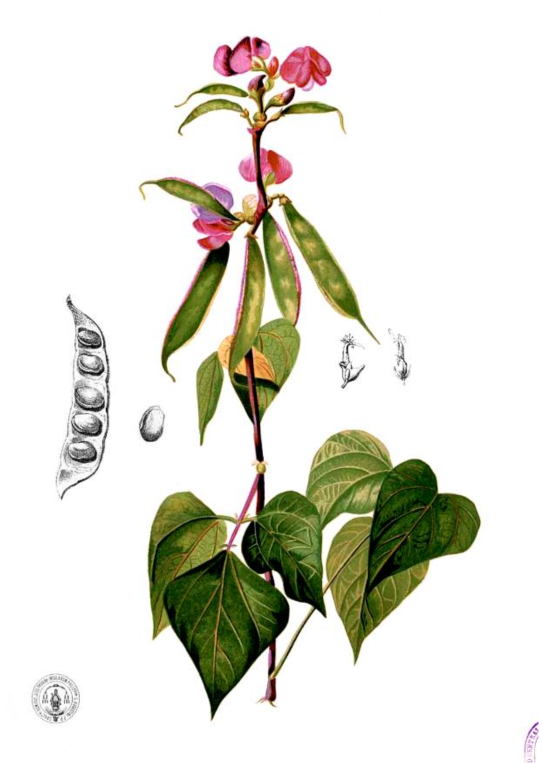

Figure 2.7: Lablab bean *(Lablab purpureus)* (source: Wikimedia.org)

Lablab grows best at average daily temperatures of 18-30°C, but can tolerate higher temperatures as well as light frosts (Cook et al. 2005).

While remains of Lablab have been found dating to 1800 BC in India (making it one of the oldest cultivated plants), recent genetic analysis points to an Eastern Africa centre of origin (Robotham and Chapman 2017). Lablab can achieve grain yields of 1-2.5 t ha^{-1}, depending on the cultivar, but when grown on trellises in smallholder systems the grain yields can be far greater. In mixtures with other crops, grain yields average 0.5 t ha^{-1} (Cook et al. 2005).

Lablab was traditionally grown as an intercrop with maize in Eastern Africa (Leakey 1936). Maize has excellent standing ability, but is easily infested by weeds; lablab efficiently fights weeds, but lodges heavily, losing a great amount of protein-rich lower leaves and decreasing its photosynthetic efficiency. Intercropping is therefore beneficial for both, since weeds are suppressed and physiologically active leaves in lablab are preserved (Mihailovic et al. 2016). In a study in Kenya, intercropping of maize and lablab greatly improved land productivity giving relative yield total (RYT) values of between 1.0 and 1.5 (Gitari et al. 2011). Similar results were found in a study from South Africa, however only when the lablab planting was delayed (relay planted) after the maize (Mpangane et al. 2004).

2.4.2.3 Pigeon pea (Cajanus cajan (L.) Millsp.)

Pigeon pea is an erect, woody, annual or short-lived perennial shrub or small tree, 1–4 m tall with a deep taproot (up to 2 m). Pigeon pea is grown across Africa for food (dried or fresh peas), fodder, and as an export crop (primarily to India); dried pigeon pea stalks can also be used as fuel wood (Cook et al. 2005) The Indian subcontinent is considered the centre of origin of pigeon pea, but a secondary centre of diversity is found in East Africa, where the crop has been grown for at least 4000 years (van der Maesen 1990).

Figure 2.8: Pigeon Pea (*Cajanus Cajun*) (source: wikimedia.org)

In Africa, the export market to India has driven an expansion in pigeon pea cultivation (in the last 20 years, the area of pigeon pea planted has more than doubled, while yields per hectare have increased by approximately 50%) (Salim 2017). According to the FAO, the average yield from across Africa from 2007-2017 was 0.94 tons ha^{-1} (FAO 2017b).

Pigeon pea is traditionally grown as an intercrop with maize in Eastern Africa (Leakey 1936), and has been referred to by some researchers as the legume that is best suited for intercropping in CA since it produces large quantities of N-rich biomass during the dry season (most of which is still present in the field at the onset of the succeeding cropping season) as well as an edible grain with good marketing opportunities (Odeny 2007; Baudron et al. 2012a). In a study in Tanzania, total grain yields of intercropped maize and pigeon pea were found to be significantly higher than those of maize and legume in sole crop treatments (a land equivalency ratio greater than 1.0 in all cases), showing a high complementarity between maize and pigeon pea crops (Rusinamhodzi et al. 2017). A study in South Africa found that intercropping of maize with pigeon pea was a useful practice towards increasing profitability of dryland cropping systems, with land equivalency ratios between 1.24 and 1.77 (Mathews et al. 2001). Similar studies in Brazil have found land equivalency ratios of up to 2.0 for intercropped maize and pigeon pea (Baldé et al. 2011). Long-duration pigeon peas in particular may play an important role in low-input maize production systems primarily through N cycling (probably through capture of deep soil N pool and litter) and through biological nitrogen fixation, which has been found to increase both maize yield and nutritional quality (Wanderi et al. 2011).

2.5 Farmer Managed Research

While some organizations and researchers continue to promote CA as an agricultural system with wide applicability across Africa (Kassam et al. 2015; Jat et al. 2016), increasing concerns about the over-promotion of CA in Africa (c.f. (Giller et al. 2009; Andresson and Giller 2012)) have led most researchers to now take a more nuanced view of CA's applicability, calling for site-specific recommendations and adaptation of CA systems to different agro-ecological environments (Tittonell et al. 2012; Corbeels et al. 2014a; Giller et al. 2015; Thierfelder et al. 2016).

This increasing realization that all agronomy is local has also led to the realization that cropping systems need to be tailored to local conditions, ideally through a process of co-design with local farmers (Husson et al. 2016). Particularly for knowledge intensive farming systems, traditional systems of technology transfer are not sufficient (Tittonell et al. 2012), and there is critical need for an active farmer participatory approach in the adaptation of CA to smallholder farming systems (Cherr et al. 2006; Serraj and Siddique 2012). If the farmer is the target than exploratory on-farm research involving the farmer must be the starting point for any programme for agricultural improvement – moving from 'technology changing farmer practices' to 'farmer practices informing agricultural innovation' (Kassam 2017). Farming systems and management practices have to be continuously adapted by farmers to changing socio-economic conditions (Martin et al. 2013), and in fact several researchers have pointed out that the real lessons to be learned are the adaptations made by farmers (Bolliger et al. 2006; Gowing and Palmer 2008). Methods like farmer managed experiments have the potential to not only increase our agronomic knowledge, but offer an efficient and cost-effective extension approach and a way to stimulate and promote farmer innovation.

3. INTERCROPPING IN CONSERVATION AGRICULTURE SYSTEMS FOR SMALLHOLDERS IN ZIMBABWE – EFFECTS ON MAIZE YIELDS AND TOTAL BIOMASS PRODUCTION

3.1 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), deteriorating soil conditions (due to poor farming techniques and limited use of soil amendments) and increasingly uncertain weather patterns (due to climatic change).

Conservation Agriculture (CA) trials as a solution to some of the challenges facing farmers in Zimbabwe were conducted at research stations in Zimbabwe 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), and his system of CA for smallholders (using manually dug planting basins and often the use of supplemental mulching material) began to be intensively promoted as a relief intervention and as a climate smart agriculture technology starting in the early 2000's (AGRITEX 2016). Brian's methods were heavily promoted by a development organization that he subsequently started (Foundations for Farming) and also picked up by other NGO's (World Vision, Christian Care) and international research centres (ICRISAT, FAO). In many cases, farmers were convinced/coerced into trying conservation agriculture by giving out free seeds or fertilizers and in some cases relief food if farmers practiced CA methods (AGRITEX 2016).

The first real challenge to this new hegemony of CA as a panacea to the agricultural challenges faced by smallholders in Zimbabwe came from an influential paper by four European researchers (Giller et al. 2009). This paper presented a very necessary check to the sometimes over-stated claims of CA advocates at the time, including identifying one of the biggest challenges to more wide-spread adoption of CA in semi-arid areas of Africa: lack of sufficient biomass to serve as a soil cover or mulch. While mulching provides many benefits for crop production in semi-arid areas, these same areas suffer from low overall biomass production due to limited and often sporadic precipitation, high mulch decomposition rates from heat and termites, and high levels of competition for mulch from livestock. Smallholder crop production in Zimbabwe is generally low – typically 1 ton ha^{-1} – and the limited amount of crop residues available typically become a public good for communal grazing after harvest, leaving only a sparse soil cover (except in the case of fenced fields, which are not common for most smallholders in Zimbabwe due to the cost of fencing materials) (Mtambanengwe and Mapfumo 2005).

Many organizations that promoted CA in Zimbabwe (FAO, ICRISAT, ACF, Foundations for Farming, etc.), 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 as such by smallholders in search of family food security) but is rarely feasible on larger areas due to the high labor demands and scarcity of available mulch (Grabowski and Kerr 2014). This has 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 (See Figure 3.1) (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.

A meta-analysis of CA studies from across sub-Saharan Africa (SSA) showed that while crop grain yields are significantly higher in CA systems, this is dependent on including both mulch and crop rotations: the two components that are, for many smallholder farmers in SSA, the bottlenecks to adopting CA (Corbeels et al. 2014b). This conclusion was echoed in a recent ex-post evaluation of 10+ years of CA promotion in Zimbabwe, where lack of mulch was identified by as the biggest obstacle to increasing area and number of farmers practicing CA (Nkala 2017).

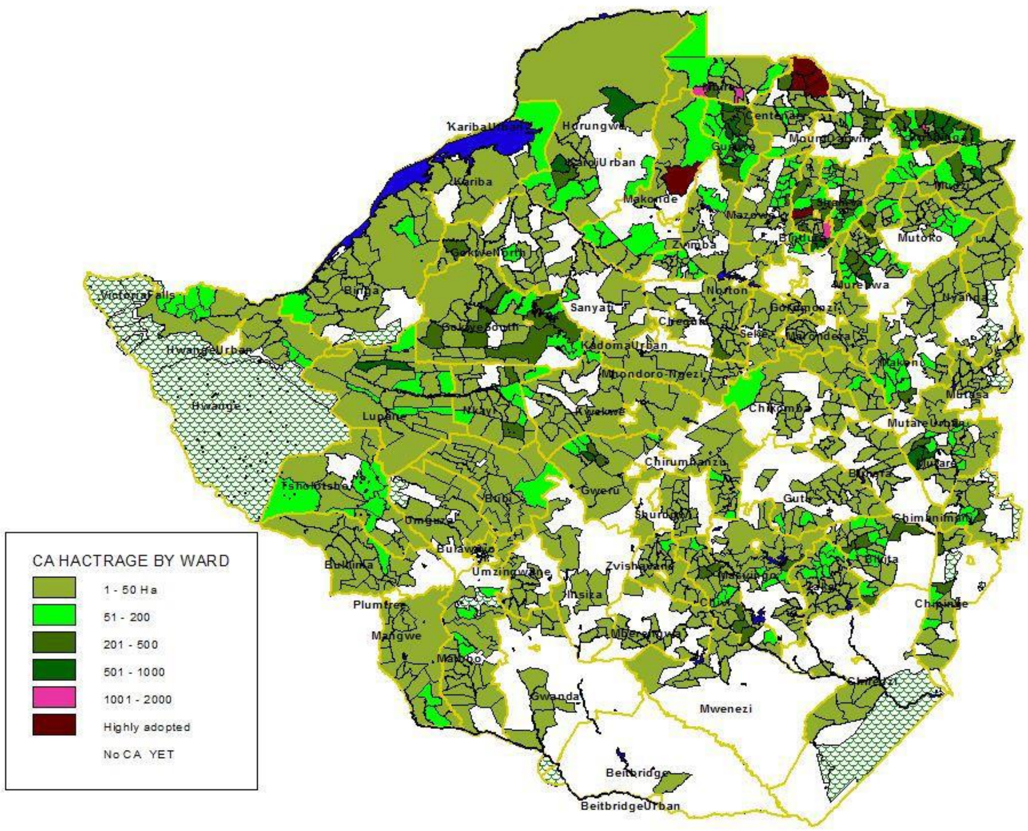

Figure 3.1: Total CA Hectarage by ward in Zimbabwe in 2015 (AGRITEX 2016)

One possible solution to this challenge of lack of mulch is intercropping the main cereal crop with a (leguminous) cover crop - cf (Rusinamhodzi et al. 2011). For example, a study from Cameroon demonstrated that crop biomass production can be doubled by intercropping a secondary leguminous crop (numerous types were tested) with maize or sorghum, 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 (Naudin et al. 2010; Baudron et al. 2012b). Adding an intercropped legume may also decrease mulch decomposition rates: Sanaullaha, Blagodatskay et al. (2011) found that the decomposition of plant residues and soil organic matter is slower under drought conditions when plants are grown in mixture compared to monocultures; while Palm, Gachengo et al. (2001) found that mixing of N rich residues (for example from intercropped legumes) with N poor sorghum residues may reduce the C:N ratio of the combined mulch, therefore avoiding potential problems of temporary N immobilization by micro-organisms.

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) along 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. These studies are overwhelmingly positive about the impacts of CA together with intercrops, particularly when the impacts on the overall farming system are taken into account (for details, see section 2.3 of this thesis).

Despite some advocates claims that legume intercropping in CA systems can eliminate the need for adding supplemental mulch in semi-arid areas of Africa, the author has been unable to find scientific studies verifying this claim. 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 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. In particular, this study is meant to answer two specific questions:

1. Can adding a legume intercrop eliminate (or at least reduce) the need to add supplemental mulch in maize based smallholder conservation agriculture (CA) farming system?
2. Can adding a legume intercrop increase the total amount of biomass produced in maize based smallholder CA systems?

I hypothesize that the living plant growth of the legume intercrop will have the same positive effect on maize yield as dead plant residue mulch, and that including an intercropped legume in maize based CA systems in Zimbabwe will both eliminate the need to add supplemental mulch, and 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.

3.2 Materials and Methods

3.2.1 Study Sites

This study was conducted with three farmers from two different areas of Zimbabwe (see Figure 3.2). Farms in the Lupane region (sites J1 and J2) are in agro-ecological zone IV, characterized by a mean annual rainfall of 450-600 mm, and a mean annual temperature of 18-24 °C (Mugandani et al. 2012). 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 (up to 75 m) of fine to medium grained sand, extremely high sand/silt concentrations and little or no reserves of weatherable minerals (Pedology & Soil Services 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 % and clay percentages between 30 and 60 %, and appreciable reserves of weatherable minerals (Pedology & Soil Services 1979). These soils are of very high agricultural potential, with the main limitation being the semi-arid local environment (Nyamapfene 1991).

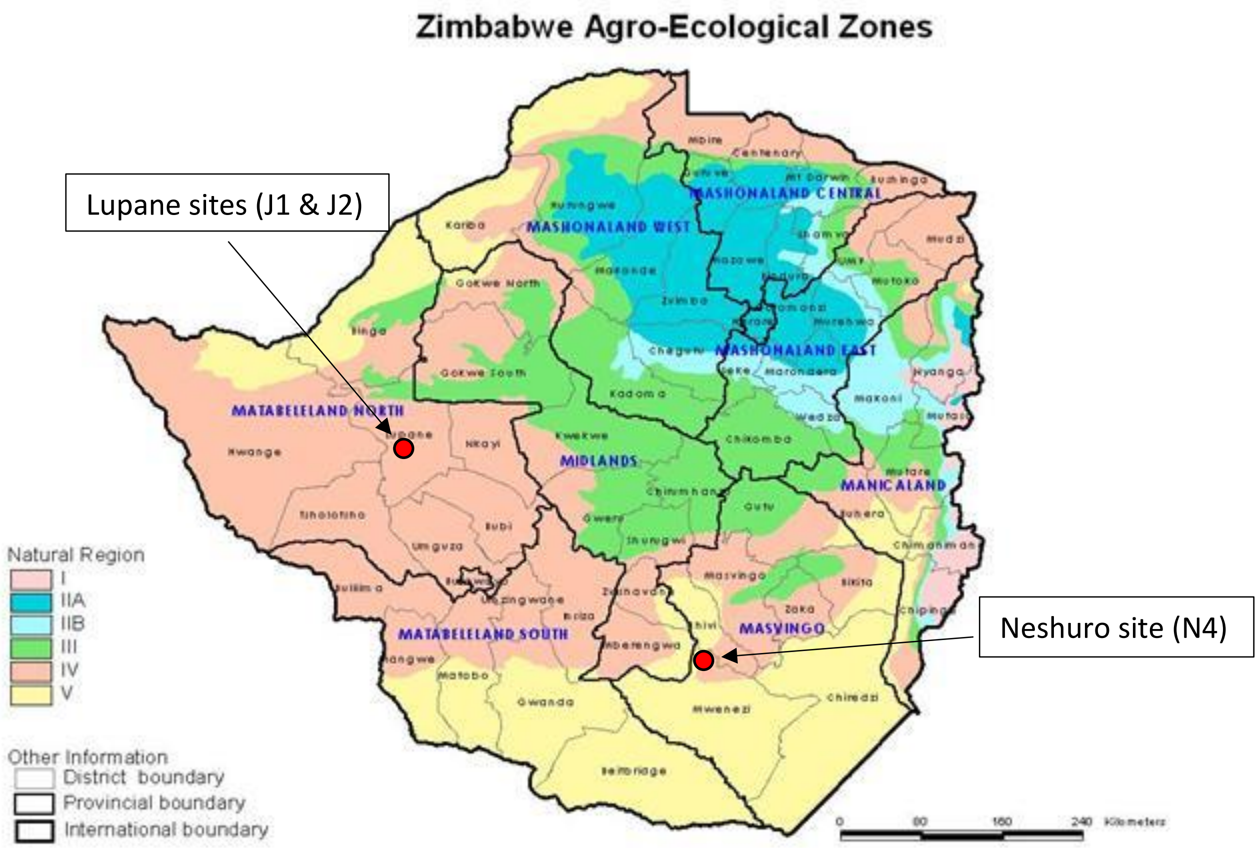

Figure 3.2: Zimbabwe Agro-Ecological Zones (source: *http://www.fao.org*)

3.2.2 Experimental Design

The experiment was initiated in late 2015 and was followed for one cropping cycle. Farmers were selected by the local 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 (see Table 3.1). Each farmer managed experiment was established on a piece of land approximately 40 m x 12 m while each treatment was approximately 5 m x 6m. Initially 8 farmer managed experiments were established in three different locations, however the data from five of these sites was judged to be unreliable and was not used in this analysis: at one site, a major flood went through the farmer's fields; at one site animals broke into the famer's fields and ate most of the growing plants; at one site the farmer did not do a sufficient job of mulching the mulched plots; and at one site germination of crops was almost zero. A fifth site was eliminated at the data analysis stage as the data was of questionable quality (many of the harvest index values of the crop species were greater than 80%). In the end, three of the sites (at two different locations) were judged to be of sufficient quality to analyze. 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 experiment were provided for the farmers by the partner NGO.

- Maize : ZM 521 OPV: white semi-flint grain maize, intermediate variety, anthesis 63-66 days; maturity 121-132 days, bred by CIMMYT, who claim that it yields 30 – 50% more than traditional varieties under drought and low soil fertility (Capstone Seeds 2016)

- Cowpea: CBC3 an upright bushy variety, cowpea grain yield for upright varieties such as CBC3 has been found to be 2-4 times higher than for more traditional climbing varieties in maize cowpea intercrops, as well as reducing the amount of competition with maize (Mashingaidze and Katsaruware 2010);
- Lablab and Pigeon pea: seeds were procured locally by the project staff from OPV varieties currently in use by local farmers

Table 3.1: Experimental Treatments

Main plot	Sub plot	Treatment name
Mulch	No cover crop	Mulched maize monocrop
	Cowpea	Mulched maize intercropped with cowpea
	Lablab	Mulched maize intercropped with lablab
	Pigeon pea	Mulched maize intercropped with pigeon pea
No mulch	No cover crop	Maize monocrop
	Cowpea	Maize intercropped with cowpea
	Lablab	Maize intercropped with lablab
	Pigeon pea	Maize intercropped with pigeon pea

Farmers received a copy of the experiment design with explanations in their local language on how to establish the experiment (see Appendix 3.1). No conventional check treatment of traditional practice (typically plowing and broadcast seeding with limited use of soil amendments) 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 planting of maize in 2015/16 died which needed to be reseeded 2-3 times in some but not all planting stations (Table 3.2). The cowpea and lablab did not require replanting. However, poor germination of pigeon pea resulted in several farmers replanting with still poor levels of .emergence.

Mulch was added to the plots using locally available sources (Table 3.2). As farmers were told to plant the experiment according to their standard practice, the type and amount of mulch added to the mulched plots varied between farmers (from ~ 4000

Figure 3.3: Hand hoe dug planting basins (before planting) in a mulched CA field in Zimbabwe**.** Source: Alden Braul

kg ha^{-1} at site J2 to ~14,000 kg ha^{-1} at site N4). Planting date also varied according to the farmers typical practice.

Planting basins were dug with hand hoes, with the basins spaced either 60 cm X 90 cm apart (sites J1 and J2) or 75 cm X 75 cm apart (site N4) (Table 3.2). Three maize seeds were planted per planting basin, and thinned to leave an average of two plants per basin. 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). Total soil disturbance is estimated at ~40%. Farmers managed the plot as per their usual practice which primarily included hand weeding.

Table 3.2: Agronomic information for the three study sites

Site	Farmer	Planting spacing	Planting dates	Mulch Type	Harvest Dates	Soil type	Notes
Lupane	Leonard Jazi	Maize: 90 cm X 60 cm planting basins (37,037 ha^{-1}) Pigeon pea & Lablab-	Maize – Nov 25, 2015 Legumes – Jan 5, 2016	Predominantly grass sedges[1] ~ 6000 kg ha^{-1} mulch	Cowpeas harvested April 8. Pigeon pea wet biomass collected but not dry biomass (still growing at	Deep Kalahari sands	Pigeon peas were replanted. Experienced CA farmer. Early frost (after maize & cowpeas matured) negatively

[1] According to the local technicians, this was grass collected from a local Ndonga dam in very dry form after the dam ran out of water over two years ago. The technicians observed that this grass absorbs a lot of water during rain showers and is not easily destroyed by termites.

		50 cm within row spacing, 2 seeds/hole Cowpea - 10 cm within row spacing, 2 seeds/hole			end of experiment).		impacted lablab and pigeon pea growth (they regrew after the frost)
Lupane	Betty	Same as J1	All – Jan 12, 2016	Predominantly grass sedges ~ 4000 kg ha^{-1} mulch	Cowpeas harvested April 12. Pigeon pea and lablab harvest not measured (experiment ended before they matured)	Deep Kalahari sands	Experienced CA farmer Early frost (after maize & cowpeas matured) negatively impacted lablab and pigeon pea growth (they regrew after the frost)
Neshuro	Rebecca Murereki	Maize: 75 cm X 75 cm planting basins (35,555 ha^{-1}) Pigeon pea & Lablab - 50 cm within row spacing, 2 seeds/hole Cowpea - 10 cm within row spacing, 2 seeds/hole	All – Jan 21	Maize stover, pearl millet, organic matter and unpalatable grass species from local hills and local veld ~ 15,000 kg ha^{-1} mulch		Sandy loams overlying vlei or wet lands	Un-mulched plot replanted several times. Some pruning of the lablab was required where maize had been replanted. Un-experienced CA farmer

The data was analyzed assuming a randomized complete block design (n=2). There was a high amount of variability observed among sites (planting date, farmer practice and management, mulch levels, spacing, etc.) and a relatively small number of data points (only 3 of the 8 original sites were deemed to be of sufficient quality to analyze). Because of this these results should not be interpreted as conclusive but as simply giving an initial response to the hypothesis. Though not ideal, justification for using this approach hinges upon the value of using farmers as research partners, and that we were looking for preliminary evidence for a concept, not conclusive results.

Intercrop biomass and yield and maize biomass and yield were all calculated 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 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 of 2016, but as funds for the experiment had ended, these samples were not dried. To use these final results, we assumed a wet weight to dry weight ratio of 4:1, 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 at all sites. However, as cow pea yields are the focus of the next chapter of this thesis, these yields are not included in the analysis for this chapter.

3.2.4 Data Analysis

Each data set was analyzed using PROC Mixed procedure with the Statistical Analysis Software program 9.4 (SAS Institute, 2013a), 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 $p < 0.05$. There were significant site, treatment, and (site*treatment) interactions at the sites (particularly for the intercrops) and therefore the data was analyzed separately for all three sites (see Table 3.3). Various data transformations were tried (logarithms, square root) but these made little impact on the analysis.

Table 3.3: Treatment means (n=2) and analysis of variance (ANOVA) for selected agronomic parameters from study sites in Zimbabwe

	Maize Biomass		Maize Grain		Intercrop Biomass		Intercrop Grain		Total Biomass	
	kg ha^{-1}		kg ha^{-1}		kg ha^{-1}		kg ha^{-1}		kg ha^{-1}	
Site										
J1 (mulched)	17,046	a	7,449	a	1,795	b	302	b	18,393	a
J2 (mulched)	15,028	b	6,250	b	2,793	a	432	b	17,123	a
N4 (mulched)	10,733	c	3,920	c	3,378	a	1,689	a	13,267	b

J1 (un-mulched)	11,708	a	4,954	a	1,204	b	136	b	12,611	a
J2 (un-mulched)	10,542	a	4,060	a	1,898	b	333	b	11,965	a
N4 (un-mulched)	9,409	a	4,080	a	3,644	a	1,844	a	12,142	a
Intercrop										
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	30	c	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	

3.3 Results and discussion

3.3.1 Weather

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 (see Figures 3.3 and 3.4).

In Hwange, 585 mm of rain distributed over 122 days was received over the course of the experimental period (November 2015 to May 2016) (World Weather Online 2018). The average annual 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.

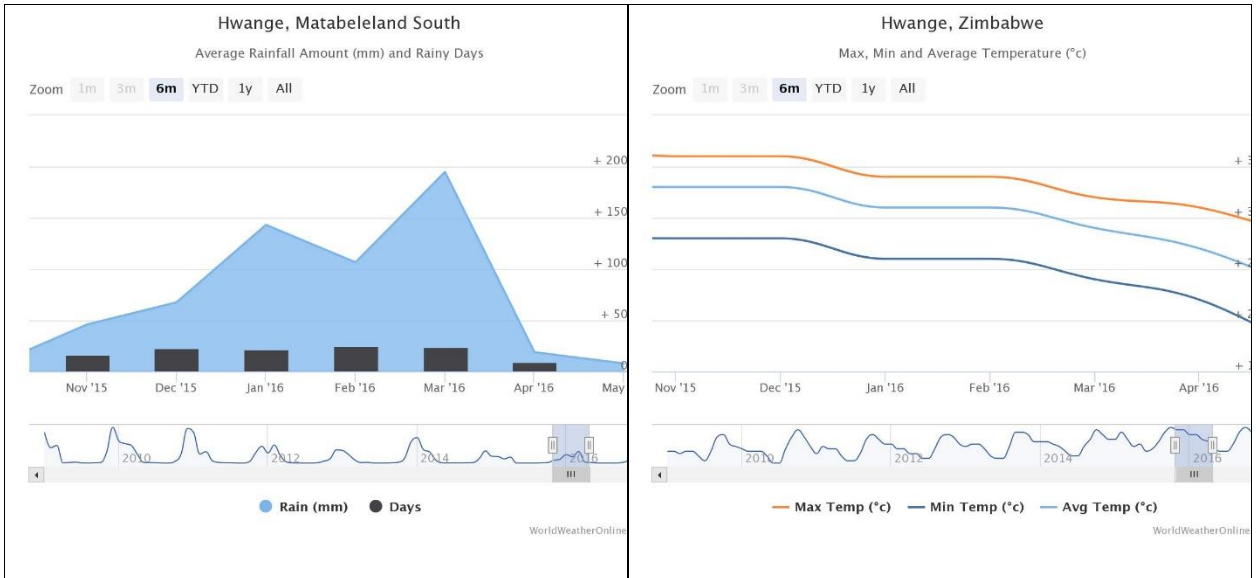

Figure 3.3: Rainfall and Temperature Data from Hwange, Zimbabwe (closest weather station to sites J1 and J2) November 2015-May 2016

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) (World Weather Online 2018). Masvingo weather station, located approximately 100 km from the 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).

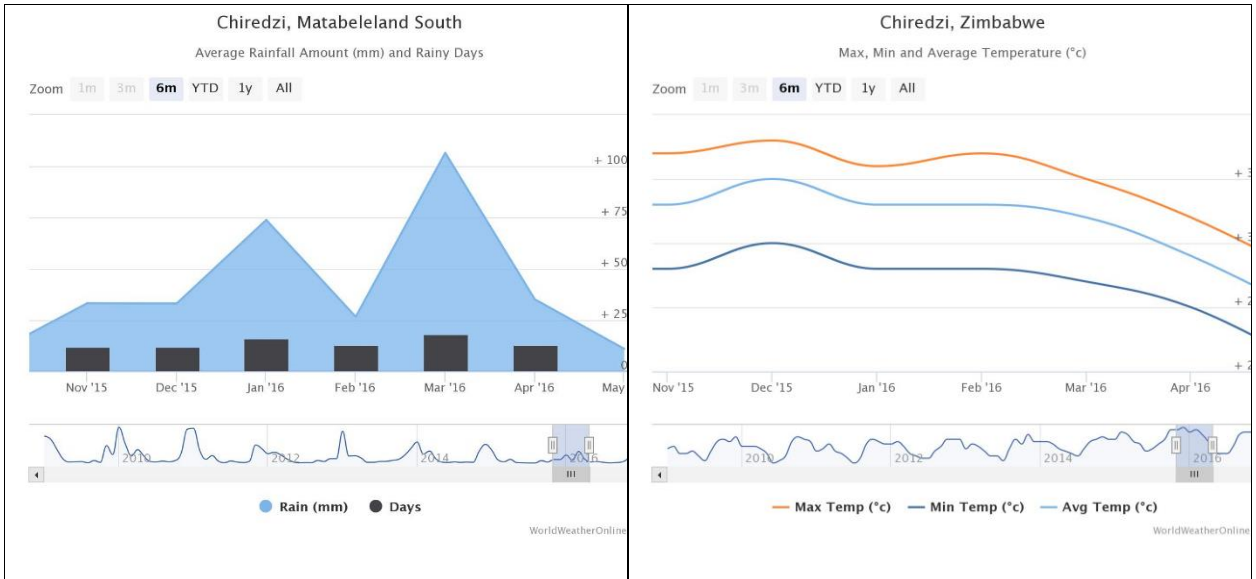

Figure 3.4: Rainfall and Temperature Data from Chiredzi, Zimabbwe (closest weather station to site N4) November 2015-May 2016

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[2] (IPC) 2 (stressed) in terms of food security in June of 2016. The IPC defines this stage as at least one in five households in the area have adequate food consumption but are unable to afford some essential non food expenditures without engaging in irreversible coping strategies. The area surrounding site N4 was in the more serious IPC phase 3 (crisis) phase (see Figure 3.5). The IPC defines this stage as at least one in five households in the target area have food consumption gaps with high or above usual acute malnutrition or

[2] 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

are marginally able to meet minimum food needs only with accelerated depletion of livelihood assets that will lead to food consumption gaps (FEWSNET 2017).

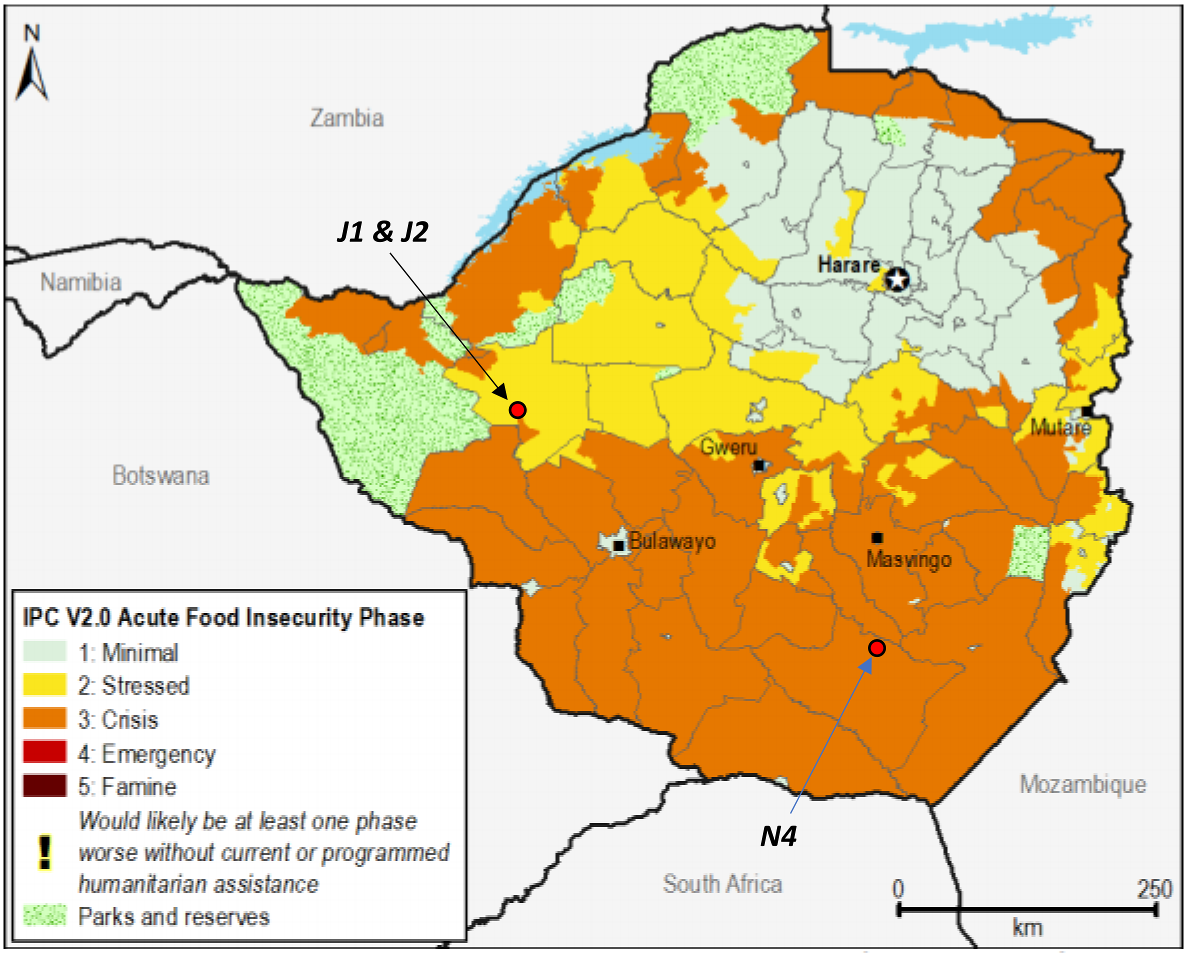

Figure 3.5: June 2016 food insecurity in Zimbabwe ((FEWSNET 2017)

This data also correlated well with the Zimbabwe Vulnerability Assessment Committee (ZimVac) report from July 2016 (Food & Nutrition Council 2016), 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 percent 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.

3.3.2 Maize Yields

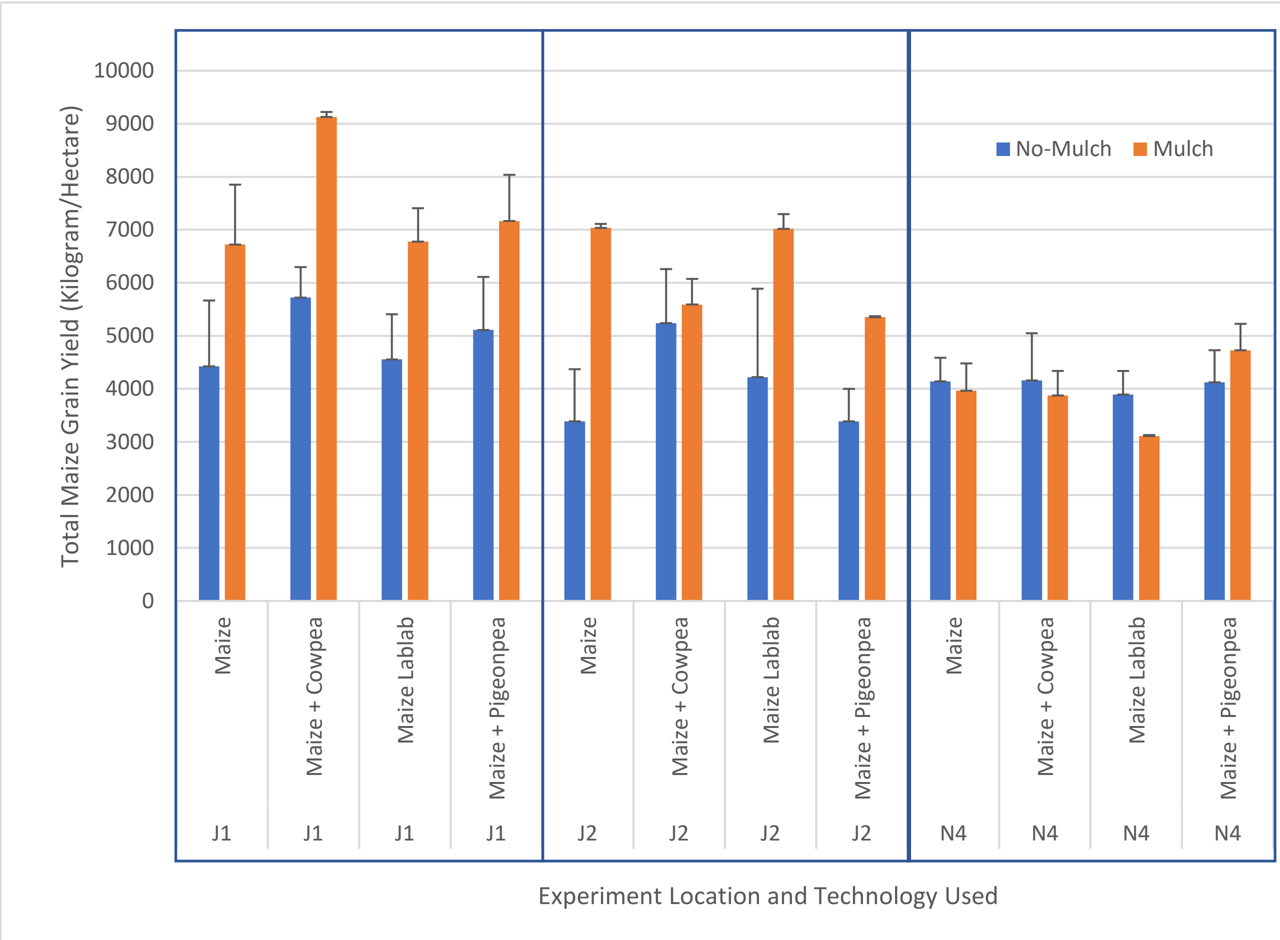

Figure 3.6: Total Maize Grain Production from various treatments and locations. Error bars indicate standard error of the means for each treatment.

Figure 3.6 shows the total maize grain production from the three sites under the different experimental treatments (only the maize yields are shown). Average grain maize yields across all treatments were highest at site J1 and lowest at site N4. For site J1, maize grain yields across all treatments averaged 6,201 kg ha^{-1} (SE 441) with a range between 3,700 and 9,200 kg ha^{-1}. For site J2, maize grain yields across all treatments averaged 5,155 kg ha^{-1} (SE 406) with a range between 2,400 and 7,100 kg ha^{-1}. For site N4, maize grain yields across all treatments averaged was 4,000 kg ha^{-1} (SE 175) with a range between 3,100 and 5,200 kg ha^{-1}.

Three important observations can be made about the differences between the maize grain yields at the different sites and treatments. First, 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 yields have been highly variable in Zimbabwe, they have generally been in decline since the 1970's; average figures for the most recent years that data is available (2004-2014) are 706 kg ha^{-1} (see Figure 3.7).

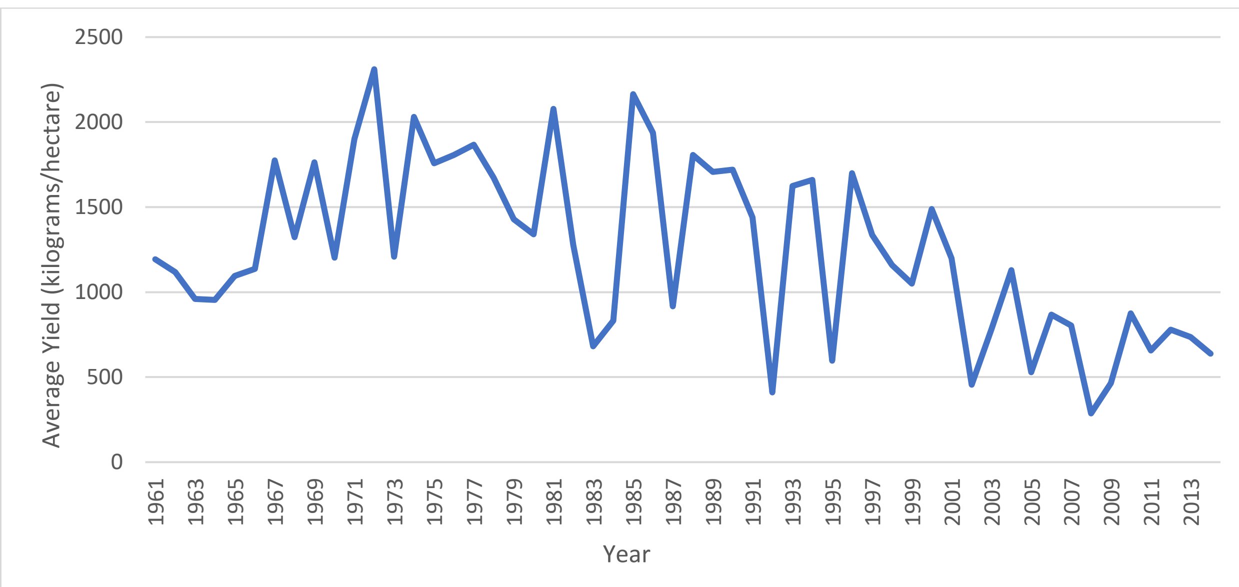

Figure 3.7: Zimbabwe average maize yields (Kg ha^{-1})
(source: http://www.fao.org/faostat/en/#home; downloaded July 24, 2017

While these are indicative results from small test plots, and 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 spacings; micro-fertilization of composted cattle manure placed close to the growing maize plant; minimal soil disturbance; and timely and thorough weeding.

Second, the average of the un-mulched treatments (essentially a CA system without added mulch) at sites J1 (4,954 kg ha^{-1}), J2 (4,060 kg ha^{-1}) and N4 (4,080) were not significantly different from each other (Table 3.2). The average of the mulched treatments (a more complete CA system) at the three sites, however, were significantly different ($p<0.0001$) among sites: the average yield for all of the mulched treatments at site J1 was 7,449 kg ha^{-1}, at site J2 it was 6,250 kg ha^{-1}, and at site N4 it was 3,920 kg ha^{-1}. The difference between sites J1/J2 and N4 is perhaps understandable given the difference among the sites in terms of weather (site N4 was hotter and drier than sites J1 and J2). Sites J1 and J2, however, likely had very similar weather (temperature and precipitation) and soil conditions. The difference in the mulched treatments between these sites may have been impacted by the total level of mulch added to the plots: the farmer at site J1 added 50% more mulch to his plots than the farmer at site J2 (~6,000 kg ha^{-1} compared to ~4,000 kg ha^{-1}).

Third, the addition of mulch increased maize yields across all treatments at sites J1 (7,449 kg ha^{-1} mulched compared to 4,954 kg un-mulched) and J2 (6,250 kg ha^{-1} mulched compared to 4,060 kg ha^{-1} un-mulched) but had no impact at site N4 (3,920 kg ha^{-1} mulched compared to 4,080 kg ha^{-1} un-mulched). In general, maize yields were greatest where growing conditions were wettest. Howevre, 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 also be related to the different soil types at the two locations: sites J1 and J2 being on sandy, relatively unfertile soil and site N4 being on a sandy loam of high agricultural potential. There is also a possibility that the farmer at site N4 added supplemental water to these research plots during the growing season. This would explain the lack of difference between the mulched and un-mulched plots, and is understandable given the general food insecurity present in some of these communities: even thought the research plots were quite small, overall they had the possibility of contributing a small but significant amount of food to the farming household (in the case of the farmer at N4, ~200 kg of maize plus the associated legume products). What I think makes most sense, however, is that the biomass production of the legume crops relative to the maize crop increased with water stress (Table 3.2). This mirrors other research results (c.f. (IDRC 1976; Natarjan and Willey 1996)) and is corroborated by the high levels of biomass production by the legumes expressed as a percentage of maize biomass production (for the un-mulched, intercropped treatments at site N4, cowpea contributed 45% of the total biomass production and lablab produced 73% of the total biomass production.

Fourth, there were no clear differences in the impacts of the three different legumes on maize grain yields. While some of the legume intercropping sites had higher maize grain yields than other legume intercropping sites (notably cowpea at site J1 and lablab at site J2) this was not consistent across sites. This was likely due to significant 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 of these cases, the pigeon peas needed to be replanted as the initial plantings did not emerge – possibly due to low quality pigeon pea seed). 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 to not 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.

Finally, to answer the research question of whether an intercropped legume can increase maize yield without adding additional mulch in semi-arid areas of Zimbabwe, contrasts were done on a site by site basis of maize grain yields between the mulched, monocropped maize plots and the un-mulched, intercropped maize plots. There was a significant difference between these treatments at sites J1 and J2. Site J1 had an overall estimated maize grain yield increase of 1,593 kg ha^{-1} (P=0.007) for the mulched, monocropped maize treatment compared to the un-mulched, intercropped treatment. Similarly, Site J2 had an overall estimated maize grain yield increase of 2,753 kg ha^{-1} (P=0.0235) for the mulched, monocropped maize treatment compared to the un-mulched, intercropped treatment. The results from sites J1 and J2 support a rejection of my initial hypothesis that adding a legume intercrop will eliminate the need to add supplemental mulch in maize (*Zea mays*) based smallholder conservation agriculture (CA) farming system. For site N4, however, there was no significant difference between the maize grain yields from the mulched, monocropped plots and the un-mulched, intercropped plots. This was surprising given that N4 was the hotter, drier, site. In addition, even the un-mulched, monocropped maize plots from site N4 averaged over 4,000 kg ha^{-1} in a year when there were widespread crop failures in the surrounding areas. As noted earlier, there is a potential that the farmer in this case provided supplemental water to the test plots during particularly dry periods: this would certainly have been possible given the relatively small size of the plots. As such, results from this site (in terms of differences between mulched and un-mulched maize yields) should be treated with caution.

3.3.3 Total Biomass Produced

The second part of this research attempted to determine if adding an intercrop to a CA system has the potential to increase the total amount of biomass produced. Total biomass production is included in Figure 3.8 below. For comparison purposes, black lines have been added to show total biomass production from the mulched and monocropped maize plots (the reference CA system in this case).

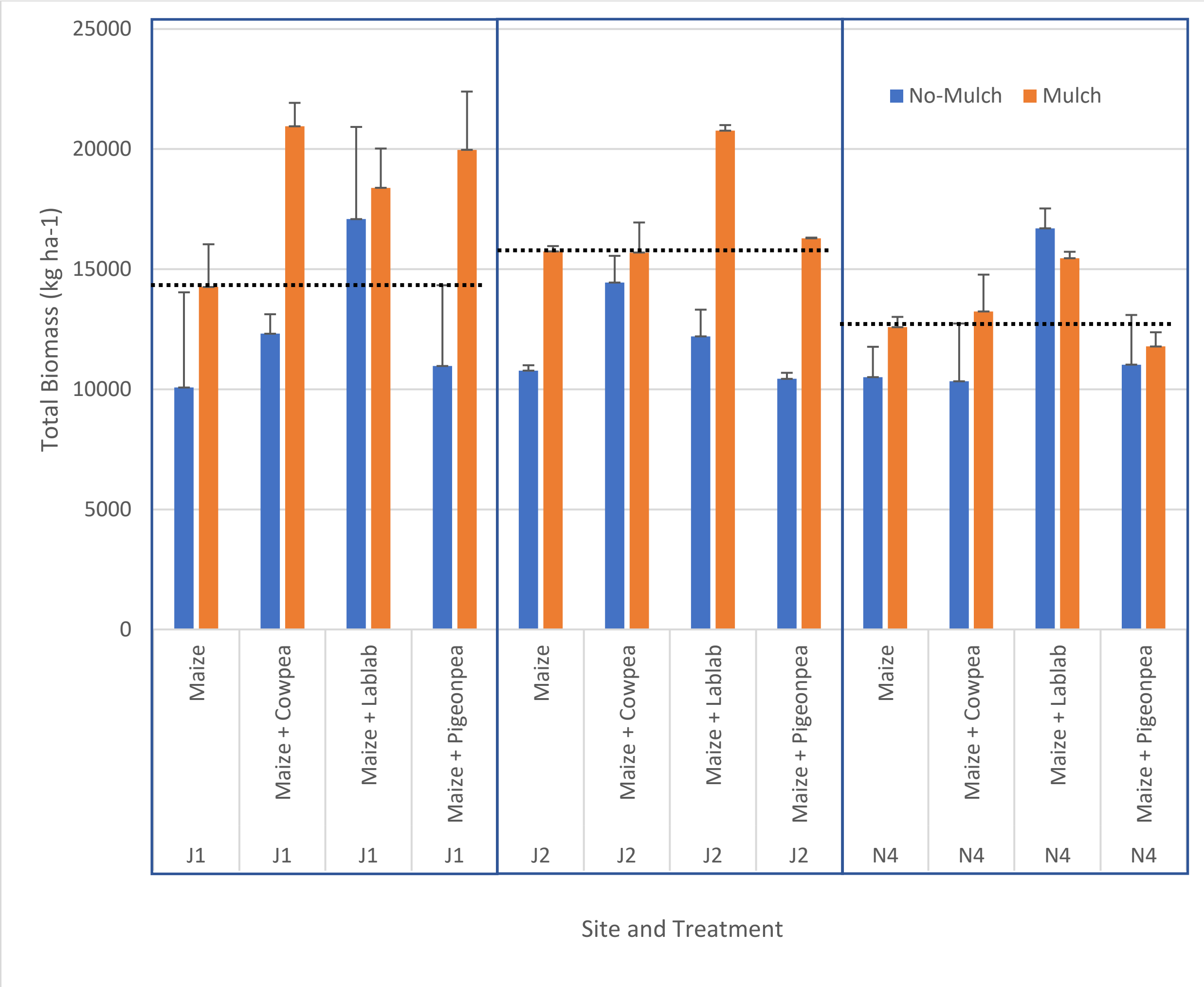

Figure 3.8: Total Biomass Production at sites J1, J2, and N4. Error bars indicate standard error for the treatments (n=2). Dotted black lines show total biomass production from the mulched, monocropped maize for the three sites.

For site J1, there was a significant increase in total biomass production, an estimated increase of 5,043 kg ha^{-1} (p=0.014) of biomass production when an intercrop was added to the standard, mulched monocropped CA maize crop. This was true for all three of the intercrop species. Similarly, for site J2 there was also a significant increase in total biomass production (an estimated increase of 1,843 kg ha^{-1} (p=0.049) of biomass when an intercrop was added to the standard, mulched monocropped CA maize crop.

There was no significant difference in total biomass production from adding a legume intercrop at site N4.

These results become more interesting when disaggregated by site, intercrop species, and the relative contribution of the intercrop species to the total amount of biomass (see Table 3.2).

Table 3.2: Proportion of total intercrop biomass compared to total maize biomass (in %) at experimental sites

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%

At all three sites, and in both mulched and un-mulched treatments, pigeon pea contributed a negligible amount in terms of total biomass of the plots. This is somewhat surprizing given that pigeon pea is a very common and profitable intercrop species with maize in other parts of Africa (notably Eastern Africa) (Senkoro et al. 2017) and that pigeon pea has been identified by some researchers as a recommended intercrop with maize under CA systems (Ngwira et al. 2012b; Rusinamhodzi et al. 2017). This is perhaps more understandable given the very low rates of germination of pigeon pea and slow growth under the maize in this experiment (as noted by the 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 were just beginning to form green pods.

At site J1 the combination of intercrop plus mulch produced some of the highest total biomass production: a total of 21.0 tons ha^{-1} for mulched cowpea, 17.4 tons ha^{-1} for mulched lablab, and 19.5 tons ha^{-1} for mulched pigeon pea. That the intercrops at this site produced the highest average contribution to total biomass is not surprising given that the intercrop in this case was planted 40 days after the maize crop: other researchers have found that highly competitive legumes such as lablab can overly compete with maize crop production if planted at the same time, and recommend either waiting 4 weeks after planting the maize to plant the lablab, or reducing the planting density of the lablab (Mpangane et al. 2004). This is less understandable given that the total contribution of the cowpea and lablab biomass was only around 10% (Table 3.2) and that the pigeon pea contributed barely any biomass at all. Further investigation here is clearly needed.

At site J2 it is important to note that the estimated increase in biomass production when an intercrop was added to the mulched monocropped CA maize crop (1,843 kg ha^{-1} (p=0.049)) is based on the average of all three legume species, while only lablab produced an actual increase at site J2 compared to the mulched, monocropped maize. While it is understandable that the addition of pigeon pea intercrop made little appreciable difference to total biomass (given that the pigeon pea intercrop produced almost no biomass at the end of the experimental period at site J2) it is surprising that the intercropped cowpea did not significantly increase total biomass production, despite the fact that it produced approximately 25% of the total biomass for the intercropped, mulched treatments (the same percentage that the lablab intercrop produced, which conversely did produce a significant increase in total biomass production at in the intercropped, mulched treatments).

Finally, while at site N4 the addition of an intercrop did not make a significant difference to the total amount of biomass produced, it did produce an increase in the amount of total biomass for the treatments with lablab. However, this increase came at the expense of maize production, as 73-82% of the total biomass production was from the lablab plants (see Table 3.2). This was the hotter, drier, site (compared to sites J1 and J2) and these conditions may have preferentially benefited lablab (which is a more drought tolerant crop than maize).

At all three sites, it is important to note that the lablab and pigeon peas will probably have continued 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 on June 22 the lablab plants were severely damaged by frost, however a month later the lablab was re-growing and flowering while the pigeon pea was not affected by the frost.) 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.

3.4 Conclusions

Question #1: can adding a legume intercrop eliminate the need to add supplemental mulch for smallholder CA systems?

This question was evaluated by comparing maize yields when grown alone (no intercrop) under a mulch regime with maize grown without a mulch but in the presence of legume intercrops. From the maize yields under mulched and intercropped experiments we found that intercrops were not an adequate substitute for mulch at sites J1 and J2. For site N4, we found, rather surprisingly, that maize yields were remarkably uniform in all research plots, and the addition of mulch (or legume intercrop) had no significant impact on maize grain yields. We thus conclude that in this first year of the experiment, adding a legume intercrop did not eliminate the need to add supplemental mulch. It remains to be seen whether there will be residual impacts of the intercrop in subsequent years.

Question #2: can adding a legume intercrop increase the total amount of biomass production in a smallholder CA system?

This question was evaluated by comparing total biomass yields from a standard CA system (monocropped maize plus mulch) to that same system with the addition of an intercrop (inter-cropped maize plus mulch). For sites J1 and J2, adding an intercrop to these smallholder CA systems significantly increased the total amount of biomass produced for sites. For site N4, there was no overall biomass increase from adding an intercrop to the system. We thus conclude that in the comparatively higher rainfall areas, adding a legume intercrop did increase the total amount of biomass production, while in the lower rainfall area it did not.

For situations where adding an intercrop does significantly increase the total amount of biomass production, it is tempting to believe their soil cover will be improved in subsequent years. A note of caution must be interjected here: while the additional legume biomass will have numerous forage, soil health, and fertility advantages, legume biomass decomposes very quickly, and post dry season soil cover can be disappointing especially when there is heavy livestock pressure. For example, a similar study done in Zimbabwe by Baudron, Tittonell et al. (2012b) on sorghum-legume intercropping concluded that while they were able to demonstrate the potential of legume intercropping to increase the production and retention of biomass in fields under CA, the amount of sorghum and legume residues that remained in on-farm experiments at the end of the dry season was relatively small.

It’s important to remember that these are results based on a small data pool and further research is needed. This will be particularly interesting when investigating the results of legume intercropping on subsequent maize crop yields. For example, studies in both Zimbabwe and Malawi found that maize grain yields when an intercrop is added to a farming system continue to increase over time (Thierfelder et al. 2012a; Ollenburger and Snapp 2014).

Finally, this study did not produce sufficient data to be able to differentiate between the three legumes species tested as to their overall benefits for farmers. While the cowpea variety tested did give a solid data set, the pigeon pea seed used had very low germination, and the experiment ended before the final biomass (and intercrop grain) from the pigeon pea and lablab could be determined.

In summary: this study gave evidence that:

- In semi-arid areas with highly variable precipitation, mulch is useful
- Intercrops plus mulch gives higher biomass in some, but not all, instances.
- Intercrops can substitute for mulch in some, but not all, instances.
- The type of intercrop and how they are planted (timing of planting compared to the maize crop) may be important in the choice of which intercrop species farmers plant, but this study did not produce sufficient data regarding which of the three legume species tested was more beneficial in this case.

4.0 ECONOMIC AND FOOD SECURITY IMPACTS OF INTERCROPPING

4.1 Introduction

The vast majority of Zimbabwean farmers are smallholders (with an average farm size of 2.5 ha) and three-fourths of these farms are on inherently infertile, sandy soils in areas which suffer from intermittent and insufficient rainfall (FAO 2017c). These small-scale, generally resource constrained farmers, need to satisfy their profit as well as their subsistence needs from the same piece of land.

While in the 1990's Zimbabwe received international acclaim for its agricultural policies and grain surpluses, since the 1990's food shortages began to be experienced at both the household and national levels, and starting in the 2000's Zimbabwe has largely been in a food insecurity crisis (Jayne et al. 2006). Over the last 25 years, the Global Hunger Index score for people in Zimbabwe has remained in the 'alarming levels of hunger' category, varying between 36.0 (in 2007-2009) and 44.7 (in 2014-2016) (Grebmer et al. 2017).

A common response to these challenges is agricultural intensification based on mimicking western, industrial agriculture. This is often stated as the only way to save Zimbabwe and the general African continent from pervasive poverty and food insecurity, and typically involves the promotion of plowing and monocultures, the use of fertilizers and agro-chemicals, and more recently GMO's and other biotechnology (Eicher 1995; Mann 1997; Quiñones et al. 1997; Ejeta 2010; Juma 2011).

Although many have challenged this dominant hegemony over the years, one of the most influential has been a white Zimbabwean farmer named Brian Oldrieve. In the mid-1980's, Brian developed a method to implement Conservation Agriculture (CA) using tools and supplies that smallholder farmers in Zimbabwe already had access to: traditional hoes, open-pollinated crop varieties, and manure or compost (although he did advocate the use of fertilizer where possible). He called this methodology *Farming God's Way* (later also known as *Foundations for Farming*). By 1989, Brian was implementing this method on his entire farm of 1,000 ha using 1,100 paid local laborers (Dryden 2009). Curiously, while Farming God's way challenged some agricultural conventions, it has continued to promote mono-cultures for 'manageability and best crop performance reasons' (Dryden 2009).

From 2004 to 2014, the Canadian Foodgrains Bank promoted Conservation Agriculture in Zimbabwe based largely on the methods espoused by Farming God's Way and Foundations for Farming[3]. While this programming has in some ways proven to be successful, significant challenges remain (Giller et al. 2009; Nkala 2017). While CA is generally considered to reduce the amount of work required to produce a given amount of maize compared to traditional, hoe based agriculture (Woodring and Braul

[3] This included the use of planting basins (which combined minimum tillage with targeted application of soil amendments), precision plant spacing, and the addition of supplemental mulch.

2011), CA methods for smallholders are still very labor intensive; so much so that the mean acreage under CA has remained at ~ 0.25 ha, with few farmers able to successfully plant more than 0.5 ha using the Farming God's Way/Foundations for Farming methodology. While these CA systems have proven to improve and stabilize maize yields, few farmers rotate their crops with legumes. As the amount of land under CA has increased, competition for biomass (to use as mulch, animal feed, thatching, and for environmental services) has also increased. These realizations have led some to conclude that while hoe based CA can improve maize yields, it is unprofitable except on small plots for farmers with low opportunity costs of household labor, and furthermore expectations of large scale adoption are unrealistic (Grabowski and Kerr 2014). Others have concluded that regardless of the production system, maize production for smallholder farmers in Southern Africa is hardly profitable due to low agricultural productivity, lack of access to markets, recurrent climate-induced shocks and economic instability (Baudron et al. 2012a; Cheesman et al. 2017). Policies and practices that overly favor basic grains production have also led to a situation where undernutrition rates for most rural Zimbabweans are poor as diets lack diversity and are poor in essential nutrients (WFP 2017).

A small but growing number of researchers are studying the integration of traditional intercropping within CA systems in part to see if this can be part of the solution to these challenges. CA maize (*Zea mays*) intercropped with pigeon pea

(*Cajanus cajan)* in Malawi was found to result in more than a double gross margin compared to conventionally grown maize (Ngwira et al. 2012b); while a study over 8 cropping seasons in Zimbabwe found that intercropped maize under CA exhibited yield benefits of 10 to 35 percent compared to continuously planted maize (Thierfelder et al. 2012b). The push-pull system of intercropping maize with a legume (typically *Desmodium sp*.), although largely for pest control purposes, has proven successful in Eastern Africa and its adoption by smallholder farmers continues to grow (Khan et al. 2011; Midega CAO 2014). In terms of food security impacts, while studies of maize-legume intercropping from southern Africa have concluded they have the potential to increase food security for vulnerable producers (Kerr et al. 2007; Snapp et al. 2010; Rusinamhodzi et al. 2012) few studies looking at the food security impacts of intercropping under CA systems exist, and none were found from the Southern Africa region specifically.

This study, which compares the effects of adding a cowpea intercrop to maize grown under a CA system for smallholders in Zimbabwe (see Figure 4.1), is designed to give evidence on the economic and food security benefits of this system, namely:

3. can adding a legume intercrop to a maize based CA smallholder farming system make it more economically productive?
4. can adding a legume intercrop to a maize based CA smallholder farming system improve its food security benefits?

This study’s hypothesis is that including an intercropped legume in CA systems in Zimbabwe will increase the total yield per unit area and the simple economic gain from the system; and that it will improve the overall food security situation of the household that depends on this farming system.

4.2 Materials & Methods

4.2.1 Economics

An analysis of the economic benefits of adding a leguminous intercrop to monocropped CA maize was done using the data collected from experimental sites described in

Figure 4.1: Maize intercropped with cowpea in Zimbabwe.
Photo credit: Alden Braul.

section 3 of this thesis (two in Lupane, and one in Neshuro, Zimbabwe). The decision was made to only use the cowpea intercrop data because the cowpea plots were the only sites that produced legume grain for all plots[4], and because cowpea is a common and widely available grain legume in Zimbabwe.

A simplified economic gain was calculated for a hypothetical 0.5 hectare (ha) plot for four different technology options:

- No-till + monocropped maize (no mulch)
- No-till + monocropped maize + mulch
- No-till + maize + cowpea (no mulch)
- No-till + maize mulch + cowpea + mulch

Taking into account the following assumptions:

- That sufficient labour and freely obtainable mulch was available to scale up the results of the experimental plot to a 0.5 ha field
- That scaling up the results from the test plots would produce similar yields;
- That buyers willing and able to pay the average cost per kilogram of commodity were available.

Prices of basic agricultural commodities is highly heterogeneous across Zimbabwe (c.f. http://www.zfu.org.zw/publications/weekly-guides for examples of

[4] For some of the sites, the experiment ended due to financial reasons before final data was collected (i.e. seed production of pigeon pea and lablab intercrops)

price variations across the country) so a variety of local sources were consulted and an approximate cost of cowpeas and maize was calculated using data from June-July, 2016[5]. These prices were cross-checked with local newspaper reports for the same period, as well as average Canadian Foodgrains Bank purchase prices in Zimbabwe for this period:

- Maize: $0.40/kg (USD)
- Cowpeas: $0.80/kg (USD)

Both the maize and cowpea variety used were open pollinated varieties, therefore it was assumed that farmers would have used saved seed from the previous season (a common practice throughout Zimbabwe). The value of the seed planted (using the same values above) was subtracted from the total value of the harvested crop. Yield data used for these calculations can be found in Figure 3.6 in Section 3 of this thesis.

4.2.2 Nutrition

The second question looked at was whether adding a leguminous intercrop to a monocropped CA plot can improve the ability of a typical Zimbabwean smallholder farmer to meet the yearly subsistence food needs of his or her family. This was done for 2 hypothetical farming areas: 0.25 and 0.5 hectare, and for the same four technology

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[5] Sites consulted for the calculation of maize and cowpea prices:
http://reliefweb.int/report/zimbabwe/zimbabwe-market-update-15-august-2016;
http://fscluster.org/sites/default/files/documents/wfp_weekly_markets_bulletin_vol_16.pdf;
http://www.zfu.org.zw/publications/weekly-guides

options and assumptions listed above. 0.25 ha represents a common land size planted under CA using planting basins in Zimbabwe; 0.5 ha represents an area under CA for an ambitious farmer or for one who has labor assistance (i.e. from other family members).

The nutritional implications of these situations were calculated using the same economic information as above, but adding a nutritional component analysis. WHO/FAO minimum dietary standards call for a diet that provides on average 2,100 kcal per person per day, 10-12% of which come from protein and 17% from fat, in addition to micronutrients such as vitamin A, iron, iodine and zinc (WFP 2018). A very simple diet based on maize and cowpeas (and the minimum amount of fortified oil and iodized salt to meet other nutrient needs) for a family of six was calculated using NUTVAL v. 4.1 (www.nutval.net) – a spreadsheet application for planning and monitoring the nutritional content of food assistance collaboratively developed by several international agencies involved in food assistance work. These particular foodstuffs were chosen because they are all part of the most common food assistance package across Zimbabwe.

This subsistence level package of food to meet the needs of a family of six for one year are as follows (amounts are rounded to the next highest 100 kg increment (maize and cowpeas), next highest 10-liter increment (oil), or next highest 1 kg increment (salt) to allow for some food wastage):

- Maize: 1000 kg (440 g day^{-1} X 365 days X 6 people)
- Cowpea: 200 kg (80 g day^{-1} X 365 days X 6 people)
- Vegetable Oil: 60 litres (25 ml day^{-1} X 365 days X 6 people)
- Salt: 10 kg (4 g day^{-1} X365 days X 6 people)

The nutritional values in NUTVAL for this diet are shown in Figure 4.1, below.

RATION CONTENTS	Daily Ration g/person/day	Energy kcal	Protein g	Fat g	Calcium mg	Copper mg	Iodine µg	Iron mg	Magnesium mg	Selenium µg	Zinc mg
MAIZE GRAIN, WHITE	440	1,606	41.4	20.9	31	1.4	-	11.9	559	68.2	9.7
BEANS, NAVY (PEA BEANS)	80	270	17.9	1.2	118	0.7	-	4.4	140	8.8	2.9
OIL, VEGETABLE [WFP]	25	221	0.0	25.0	0	-	-	0.0	-	-	-
SALT, IODISED [WFP]	4	0	0.0	0.0	-	-	160	-	-	-	0.0
Ration totals:	549	2,097	59	47	148	2.0	160	16.3	699	77.0	12.6
Beneficiary requirements for: Whole Population		2,100	52.5	40.0	989	1.1	138	32.0	201	27.6	12.4
% of requirements supplied by ration:		100%	113%	118%	15%	186%	116%	51%	348%	279%	102%
% of energy supplied by protein or fat:			11.3%	20.2%							

Figure 4.2: Nutritional Value of the basic diet used in this analysis as calculated using NUTVAL version 4.1 [screen shot from program]

The price of oil and salt was calculated using the same methodology used for calculating the price of maize and cowpea (see above):

- Oil: $ 1.50 (USD) per liter
- Salt: $ 0.50 (USD) per kilogram

Cowpea leaves (which are widely eaten in Zimbabwe) were assumed to add micronutrients and to improve the overall quality of the diet, but were not included in these calculations.

Calculations were done assuming minimal waste and an idealized market situation. The value of seeds was subtracted from the total production of maize and cowpea. If the total economic value of crops produced were higher than the costs of buying this subsistence package of food, then a net economic benefit was recorded. If the total economic value of crops produced were lower than the costs of buying this subsistence package of food, then a net economic deficit was recorded. Results are represented in dollar values; either positive (more food value produced than needed by the household) or negative (insufficient food value produced to cover the cost of the subsistence package of food). Differences between treatments was tested using the GLM procedure (due to the use of multiple sites) with the Statistical Analysis Software program 9.4 (SAS Institute, 2013), and considered statistically significant at $p < 0.10$.

4.3 Results and Discussion

4.3.1 Economics

There were significant site, treatment, and (site*treatment) interactions for the sites (particularly for the intercrops) and therefore the data was analyzed separately for all three sites. The intercropped, un-mulched maize plots as well as the intercropped, mulched maize plots both had yield increases due to the intercrop, calculated as (yield of maize + cowpeas grown together as an intercrop / yield of monocropped maize) of close to 1 or higher (see Table 4.1). These results are similar to a maize-cowpea intercropping study in neighbouring Mozambique (not using CA) which found Land

Equivalency Ratios (a slightly different, but similar ratio) of 1.4 to 2.4 (Rusinamhodzi et al. 2012).

Table 4.1: Cowpea yields and grain yield increase (expressed as ratio of maize intercropped with cowpeas compared to sole-cropped maize) in mulched and un-mulched plots

Site	un-mulched		mulched	
	Cowpea Yield (kg ha^{-1})	Total Change	Cowpea Yield (kg ha^{-1})	Total Change
J1	407 (SEM 148)	1.38	907 (SEM 315)	1.49
J2	1000 (SEM 37)	1.84	1296 (SEM 111)	0.98
N4	2200 (SEM 244)	1.54	2156 (SEM 67)	1.52

However, cowpeas are generally worth twice as much on the open market in Zimbabwe as maize: in June of 2016, maize sold for ~0.40 USD kg^{-1}, while cowpeas sold for ~0.80 USD kg^{-1}. In terms of net benefit therefore, adding cowpeas as an intercrop at all sites – for both mulched and un-mulched plots – yielded higher net economic benefits for a hypothetical 0.5 ha field, using yield data extrapolated from the test sites (see Table 4.2, below - detailed calculations used can be found in Appendix 4.5).

Table 4.2: Economic value (USD) of crops produced on a hypothetical 0.5 ha CA plot. (All figures are mean values per site).

Technology	Site	Maize Value	Cowpea Value	Total Value
Maize (no mulch)	J1	$ 881	$ 0	$ 881
	J2	$ 674	$ 0	$ 674
	N4	$ 825	$ 0	$ 825
Maize + Cowpea (no mulch)	J1	$ 1,141	$ 151	$ 1,291
	J2	$ 1,044	$ 388	$ 1,432
	N4	$ 828	$ 868	$ 1,696
Maize + Mulch	J1	$ 1,341	$ 0	$ 1,341

	J2	$ 1,404	$ 0	$ 1,404
	N4	$ 789	$ 0	$ 789
Maize + Mulch + Cowpea	J1	$ 1,822	$ 351	$ 2,173
	J2	$ 1,115	$ 507	$ 1,621
	N4	$ 772	$ 850	$ 1,622

The combination of maize and supplemental mulch and intercropped cowpea produced the highest net economic benefit for all three sites. For the cropping season studied, this combination of maize + mulch + cowpea compared to the conventional practice of un-mulched, monocropped maize produced 247 % more in potential economic benefit for the farmer at site J1 (p = 0.09), 241 % more at site J2 (p = 0.056), and 197 % more at site N4 (p = 0.034).

Interestingly, while adding both technologies (mulch and intercropped cowpea) was beneficial at all sites, the results of adding *either* one of the two technologies alone (either supplemental mulch, or a cowpea intercrop) was not simply half of the benefit of using both technologies, and had different impacts at the different sites.

Using the first technology option alone (adding supplemental mulch to monocropped maize) had different effects at site J1 and J2 compared to site N4. The farmer at site J1 could have produced 152 % more in economic benefit ($1,341 compared to $881, p=0.006), and the farmer at site J2 could have produced 208 % more in economic benefit ($1,404 compared to $674, p=0.057) from adding supplemental mulch to their monocropped maize. The farmer at site N4 however, would have seen minimal impact from adding supplemental mulch to their monocropped maize: $789 in potential benefit from the mulched maize, compared to $825 from the un-mulched maize. So for sites J1 and J2 (the sites from the Lupane region) which had comparatively more rainfall but had sandier soils of lower agricultural potential, adding supplemental mulch to monocropped maize was economically beneficial, while for site N4 (the Neshuro site) where soils were of higher agricultural potential adding supplemental mulch to monocropped maize was not found to be economically beneficial. As already noted in chapter 3 of this thesis, this was surprising given that site N4 (Neshuro) was the hotter, drier, site during the time of this study.

Using the second technology option alone (adding intercropped cowpeas but not adding supplemental mulch) was found to be beneficial at all three sites (see Table 4.2). The farmer at site J1 could have produced 147 % more in economic benefit ($1,291 compared to $881, p=0.008), the farmer at site J2 could have produced 213 % more ($1,432 compared to $674, p=0.05) and the farmer at site N4 could have produced 206 % more ($1,696 compared to $825, p=0.03). This is because while maize yields (and therefore economic benefit) were similar for all four technology options at site N4, adding a cowpea intercrop gave an additional economic benefit from the cowpea seed produced.

These observations indicate that in areas where mulch is severely limited (either through lack of supply or lack of labor to secure and spread the mulch) adding a cowpea intercrop may give similar net economic benefits as adding mulch for some sites, and superior economic benefits for others. For farmers who must choose between putting energy into a leguminous intercrop or buying/collecting and spreading mulch, choosing a leguminous intercrop may have other agronomic benefits, such as pest-suppression and soil organic carbon sequestration (see Section 1 of this thesis). In a moisture constrained year, choosing an intercrop may also make a significant contribution to household economics (and/or food supply – see nutrition section below). It should also be noted that this analysis does not take into account the differing amounts of work needed for the two technology options above (supplemental mulch and an intercropped cowpea). Collecting, transporting, and spreading mulch is very costly in terms of labour required, and although not specifically quantified, observations from Canadian Foodgrains Bank partners from across southern Africa indicate that intercropping is much less costly in terms of labour requirements.

Intercropping with a legume may also have beneficial impacts in subsequent cropping seasons: for example, a study from Zimbabwe found that sole maize planted following a maize legume intercrop produced 20% more grain yield with an 82% higher grain N content (Jeranyama et al. 1997). Despite other studies from Southern Africa that have concluded that intercropping with cowpeas is a promising and profitable option for resource-poor smallholders c.f. (Rusinamhodzi et al. 2012; Masvaya et al. 2017; Mupangwa et al. 2017), scientific and popular opinions remain mixed. For example, Waddington, Mekuria et al. (2007) reported that low input sole maize was more profitable than when intercropped with cowpea; although this was probably because at the time of the study low input sole maize was more attractive due to low costs and a higher selling price than legumes in Zimbabwe (Rusinamhodzi et al. 2012). Regardless, opinion amongst farmers remains mixed, with many believing that rainfall patterns in Zimbabwe are not conducive to intercropping with resulting competition between the two crops and overall yield losses (Norton 2018).

4.3.2 Nutrition

The ability of all the farming households to either produce and buy a very basic food subsistence package is detailed in Table 4.3 (for the hypothetical land size of 0.5 ha) and Table 4.4 (for the hypothetical land size of 0.25 ha). It is understood that this diet is only the minimal required, and is far from ideal. It also assumes the addition of some additional commodities (especially fruits and vegetables) to provide essential micronutrients for longer-term health maintenance. This is justified due to the average Zimbabwean diet being based on a standard meal of maize and beans. In neighboring Malawi, for example, it is estimated that greater than 80% of the populations calories come from maize (Ngwira et al. 2012a). Also, except in the case of the poorest households, supplemental food such as fruits, other vegetables, and a small amount of meat may be available from fruit trees, kitchen gardens, livestock production, etc.

Numbers in the chart below reflect the value (in USD) of the maize and cowpea harvest *after* subtracting the subsistence grain needs of the family calculated above. The final net economic number also reflects the subtraction of an additional amount to buy oil and salt for the year ($95 USD in all instances). For the maize, cowpea and soil and salt columns, numbers in regular font indicate a surplus of production which can be sold, and italicized numbers in parentheses show a deficit of production indicating that these commodities must be bought. More complete details on these calculations can be found in Appendix B of this thesis.

Table 4.3: Annual profit:loss calculations (USD) assuming purchase of minimum food needs for a family of six, for a variety of technology options on a CA plot of 0.5 ha.

Technology (0.5 ha plot)	Plot	Maize requirements	Cowpea requirements	Oil & Salt requirements	Total surplus or *(deficit)*
Maize (no mulch)	J1	$ 481	*($ 160)*	*($ 95)*	$ 226
	J2	$ 274	*($ 160)*	*($ 95)*	$ 19
	N4	$ 425	*($ 160)*	*($ 95)*	$ 170
Maize + Cowpea (no mulch)	J1	$ 741	*($ 9)*	*($ 95)*	$ 636
	J2	$ 644	$ 228	*($ 95)*	$ 777
	N4	$ 428	$ 708	*($ 95)*	$ 1,041
Maize + Mulch	J1	$ 941	*($ 160)*	*($ 95)*	$ 686
	J2	$ 1,004	*($ 160)*	*($ 95)*	$ 749
	N4	$ 389	*($ 160)*	*($ 95)*	$ 134
Maize + Mulch + Cowpea	J1	$ 1,422	$ 191	*($ 95)*	$ 1,518
	J2	$ 715	$ 347	*($ 95)*	$ 966
	N4	$ 372	$ 690	*($ 95)*	$ 967

Table 4.4: Annual profit:loss calculations (USD) assuming purchase of minimum food needs for a family of six, for a variety of technology options on a CA plot of 0.25 ha.

Technology (0.25 ha plot)	Plot	Maize requirement	Cowpea requirement	Oil & Salt requirement	Total surplus or *(deficit)*

Maize (no mulch)	J1	$ 41	*($ 160)*	*($ 95)*	*($ 214)*
	J2	*($ 63)*	*($ 160)*	*($ 95)*	*($ 318)*
	N4	$ 12	*($ 160)*	*($ 95)*	*($ 243)*
Maize + Cowpea (no mulch)	J1	$ 170	*($ 85)*	*($ 95)*	*($ 9)*
	J2	$ 122	$ 34	*($ 95)*	$ 61
	N4	$ 14	$ 274	*($ 95)*	$ 193
Maize + Mulch	J1	$ 270	*($ 160)*	*($ 95)*	$ 15
	J2	$ 302	*($ 160)*	*($ 95)*	$ 47
	N4	*($ 5)*	*($ 160)*	*($ 95)*	*($ 260)*
Maize + Mulch + Cowpea	J1	$ 511	$ 15	*($ 95)*	$ 432
	J2	$ 157	$ 93	*($ 95)*	$ 156
	N4	*($ 14)*	$ 265	*($ 95)*	$ 156

Results show that for farmers with enough resources to be able to plant a 0.5 ha plot, all four options (un-mulched monocropped maize, un-mulched intercropped maize, mulched monocropped maize, and mulched intercropped maize) at all three sites (J1, J2 and N4) could provide enough to meet their family subsistence food needs for the year.

At all sites, each addition to the farming system (addition of mulch, addition of a cowpea intercrop) increased the net economic benefit to the farmer. For a 0.5 ha plot, the base technology (monocropped maize with no mulch) was able to hypothetically produce enough food for a family of six for the year at all three sites plus a small average (of the three sites above) profit of $138 USD (although this was highly heterogeneous, ranging from a marginal $19 in profit at site J2 to $226 in profit at site J1). Adding supplemental mulch to these plots could have increased average (of the three sites above) profits at the three sites to $523 (ranging from $134 at site N4 to $749 at site J2). Adding intercropped cowpeas to the un-mulched maize would potentially have increased profits more than adding supplemental mulch: the average (of the three sites above) profit from adding cowpeas was $818 (ranging from $636 at site J1 to $1041 at site N4). The most profitable option on average, however, was using both supplemental mulch and intercropped cowpea, with an average (of the three sites above) profit of $1,150 (ranging from $966 at site J2 to $1518 at site J1).

For farmers for whom the maximum plot size possible is 0.25 ha, conventional practice alone (monocropped maize) would not have produced enough to meet their family's subsistence food needs for the year. Adding supplemental mulch alone would have increased maize production enough to meet a family's food needs for the farmers at site J1 and site J1 (with minimal amounts of surplus production). Adding supplemental mulch alone would still have left the farmer at site N4 in a food deficit for the year. On the other hand, adding intercropped cowpeas alone would have allowed the farmers to meet their family's food needs for the year at all three sites (with no or minimal amounts of surplus production). The combination of supplemental mulching and intercropping with cowpea was the most advantageous at all three sites, and could have produced enough to meet the subsistence food needs of their family at all three sites plus some surplus production.

Although it was not quantified, each technology addition requires an extra investment in time and labor; mulching requires gathering and spreading of the mulch, intercropping requires planting and harvesting. However, in both cases this is at least partially offset by a reduction in weeding requirements reported by the farmers in this study. (A similar intercropping study in neighboring Malawi also found that legume intercropping reduced labor requirements for weeding, while contributing substantially to the profitability to the maize-based cropping system and household food security) (Chamango 2001).

While the economics of small-holder CA farmers are generally positive, they are also highly heterogeneous and need to be considered on a case-by-case basis (Pannell et al. 2014). This is probably even more so when an intercrop is added to the system. For example, for the farmers at site J1 and J2 the results of using either supplemental mulch or a cowpea intercrop were roughly similar in terms of overall profit. For these farmers, the choice of using either or both technologies would have depended on proximity to markets and their ability to sell surplus maize and/or cowpeas, the amount of land they had available, access to mulch and the amount of labour required to collect, transport and spread the mulch, and household labour availability. For the farmer at site N4, adding a cowpea intercrop was much more advantageous than adding supplemental mulch. Whether this was an anomaly based on the specific year and weather conditions of the study is unclear, but if these results were because of lack of rain at site N4, and given the precipitation trends and predictions for southern Africa more generally, it would seem that for farmers forced to choose between adding supplemental mulch and adding an intercrop would over time be the better option.

While crop diversity may increase nutritional impacts at the farm level, this relationship is also complex, and varies depending on the accessibility of a farm and access to markets, as well as gender and control of household decisions (Jones et al. 2014). As such, while these results give some preliminary ideas on the potential impacts of intercropping on small-scale CA farmers, they should be balanced by actual case studies based on full size CA plots, and/or longer-term research.

It is important to note that these results are from a low rainfall year (local farmers referred to the growing season as a drought year) and that there was widespread food insecurity in the areas of these test sites during and after the time of the experiment, in some cases requiring external food assistance. In drought stressed years such as this, a legume crop such as cowpea typically does better because of reduced competition for moisture and light from a cereal crop (Fischer 1976). This reduced risk aspect is an important one for smallholder farmers: for example, even though there are cases where growing cowpea alone may be more profitable, small-scale farmers in Africa typically do not have the capacity to take risks nor enough land to conveniently diversify cropping by putting different sole crops on several plots (Jodha 1979). In addition, sole crop cowpea often requires one or two sprays of insecticide to control insect pests which may not be an option for small-scale farmers, while intercropping can reduce insect damage to the legume component of an intercrop and thus potentially reduce the amount of insecticide needed (Singh and Ajeigbe 2002).

4.4 Conclusions

Question 1: can adding a legume intercrop to a smallholder CA based farming system make it more economically productive?

For smallholder farmers in two semi-arid areas of Zimbabwe, this study provided preliminary indications that adding a leguminous intercrop to a CA farming system (in this case adding cowpea to a mulched maize crop) could be more economically productive, although this was dependent on the site, and ranged from a 16% increase in profitability at site J2 to over 100% increase in profitability at site N4. This study also gave preliminary evidence that adding either an intercrop or supplemental mulch to such a CA based farming system was more profitable than un-mulched, monocropped maize, and that this effect was additive (adding both mulch and an intercrop was the most profitable option). While adding supplemental mulch was not economically advantageous at all three sites, adding a cowpea intercrop alone (comparing un-mulched maize to un-mulched, intercropped maize) was economically beneficial for farmers at all sites, ranging from 45 % more profitable at site J1 to over 100% more profitable at sites J2 and N4. This is especially important given that some legumes do better in drier years than maize, and therefore adding a more drought tolerant legume such as cowpea or lablab may provide an economic stabilizing impact for farmers in drier years (Monyo et al 1976, Ewansiha & Singh 2014).

Question 2: can adding a legume intercrop to a smallholder CA based farming system improve its' food security benefits?

In October of 2016 (in the period following the harvest period of this research) assessments by the UN found that 42% of Zimbabwe's rural population was food insecure, and that this situation was worse in the arid and semi-arid areas where this research took place[6]. This research gives us an indication that farmers in these areas, even in a drought year, could produce enough food for household food security using intercropped, mulched CA provided they had the land and labour to practice CA on at least a 0.25 ha plot. Adding a cowpea intercrop increased the food security benefits for farmers at all three study sites, but comparatively more at the drier site, indicating potential resilience benefits for farmers facing increased levels of drought under climate change.

[6] http://fscluster.org/sites/default/files/documents/zim_hrp_final_web_14_sept_2016_0.pdf

5. FINAL DISCUSSION & CONCLUSIONS

5.1 History of Intercropping in Africa

Writing in 1936, LM Leakey gives us a description of traditional planting systems in Kenya:

Let us imagine that a Kikuyu has an acre of ground available for planting at the beginning of the long rains. He plants over the whole area maize, beans of two kinds, and tree-peas [Pigeon Pea]. In planting these the maize and the tree-pea seeds are put in first, irregularly all over the plot, and in a few days – when the seedlings have appeared – the two varieties of beans are planted, again quite irregularly, in the gaps between the maize and pea seedlings. In a few days the bean seedlings also appear, and then cuttings of sweet potato vine are put in all among the growing seedlings of the various other crops.

One of the varieties of beans that is planted is a very quick-growing plant, and this is harvested long before anything else is ready [Mung Bean]. This bean is never stored away in granaries for use at a later date, but is consumed more or less at once, and provides the family with fresh food, which – with the sweet potatoes planted at the beginning of the previous short rains, and which are just beginning to yield – is very welcome as a supplement to food made from dried crops from the granaries.

This bean having been uprooted and harvested the plot of ground is now left with maize which is rapidly coming into flower, the tree-peas which are very slowly growing, the sweet potato vine which is slowly making a carpet of green vine all over the ground, and finally the *slower growing variety of bean [Lablab]. Before long the rains are over and the hot season starts. The maize is harvested leaving the sweet potatoes, tree-peas and the other variety of bean in possession of the soil. The sweet potato vine has by now completely covered the ground, and it prevents the violent heat of the dry season from sucking up all the moisture from the soil. Even at the driest time of the year if you dig into the soil in a field covered with sweet potato vine, you will find that it is damp quite near the surface. This aided, the slow growing bean can withstand the hot season and continue to grow. The slow-growing bean goes on flowering and producing a crop for a long time, and can often be seen with dry pods ready to be picked, green pods and flowers all on the same plant at the same time. This bean is also particularly valuable to the Kikuyu as it yields a very succulent form of spinach.*

During the dry season very violent thunderstorms accompanied by an hour or two of torrential rain are not uncommon. As I have already pointed out the majority of Kikuyu cultivation is on the slopes of hills. The carpet of sweet potato vine prevents these violent storms from washing the soil down into the streams below, and at the same time it conserves the moisture which results from these storms.

When the dry season is nearly over the tree-peas are harvested but instead of being up-rooted they are roughly pruned, and left to stand during the succeeding short rains, when they flower a second time and produce a second crop at the end of the next dry season. The sweet potato vine also starts yielding a crop just at the end of the first dry season following the rainy season in which it was planted and goes on yielding right through the succeeding short rains.

With the coming of the short rains a second plot of ground – which had been prepared for planting during the dry season – is planted very much in the same way as before, only the tree-pea is replaced by eleuysine and millet, and meanwhile the plot planted during the previous long rains continues to yield its harvest of sweet potatoes, spinach, and slow-growing beans.

This emphasis on diversity within the cropping system is by no means unique to Kenya, nor only to crops. Writing a half-century later, Okigbo and Greenland (1976) describe the diversified agricultural enterprise of a typical African farmer:

…a farmer on an upland welldrained soil may operate a compound farm close to his homestead while at the same time maintain two or more plots under cropping systems of different periods of forest, bush, or planted fallows at varying distances from his home. In addition to this, he may practice flood land cultivation in the flood plain of a nearby river or stream. He may also raise goats, sheep and/or poultry for manure and other purposes. The cropping on the compound farm often involves major staples, vegetables and condiment plants grown in double, relay, and mixed intercropping patterns under the canopy of tree crops such as oil palms (Elaeis guineensis), mangoes (Mangifera sp.), and oranges (Citrus sp.).

Arnon (1972), in his epic tome on crop production in the dry regions, states *'in East Africa, it is exceptional for peasants to sow pure stands*' and that '*in Africa, pigeon-peas [Cajanus cajan] are frequently planted at the end of the rotation as a restorative crop, or are intercropped with maize*'. Ogindo and Walker (2005) noted that while maize is the staple food for smallholder farmers in Southern Africa, it is commonly grown in association with beans (*Phaseolus vulgaris*), and this system has been adopted by the majority of smallholder farmers to reduce risks and improve diet. In West Africa, it is claimed that intercropping cereals with grain legumes is common in over 90% of fields, with cowpea (*Vigna unguicalata*) and groundnut (*Arachis hypogaea*) being the most common legume components (Tarawali et al. 2002). A CIMMYT informational brochure claims that cowpea is widely planted in Zimbabwe, usually intercropped with maize (Waddington et al. 2002).

More quantitative data on the importance of intercropping for smallholder farmers is found in a variety of sources. Norman, writing in 1974, found that in northern Nigeria sole cropping was only practiced on 17% of farmland. Vandermeer (1989) claimed that in Africa 98% of cowpeas are grown in association with other crops, and that 94% of the cropland in Malawi is devoted to intercropping. Tittonell's (2007) study from the highlands of western Kenya found that maize intercropped with beans represents the major cropping system, occupying c. 75% of the area of smallholder farms.

These (generally older) reports tend to contradict other (generally newer) reports. Colleagues of the author have frequently told him they rarely see evidence of intercrops in African fields. A study in the early 2000's found that most farmers in Malawi do not practice crop rotation or intercropping because of the lack of availability of seed and dysfunctional markets for produce (Snapp et al. 2002). Legumes are believed to be not widely grown in Zambia under CA due to a lack of knowledge about the benefits of crop rotation and associations (Thierfelder and Wall 2010) and a lack of knowledge on how to include them in CA systems (Snapp et al. 2010).

It may be that fewer farmers in Africa are practicing intercropping. It may also depend on perspective. There is a general pattern of not explicitly defining what is meant by intercropping in many of these reports, leading to confusion over what minimum percentage of a second crop qualifies a system to be called intercropped, or what is the line between relay cropping and intercropping. It may also depend on where you are looking. For example, a 1992 study of smallholder farms in southern Malawi found that 95% of the total farm area was intercropped to various degrees, with 99.8% of the pigeon pea and 100% of the cowpea crops planted as intercrops (Shaxson and Tauer 1992). This is corroborated by other studies done in *southern* Malawi which also found a high percentage of farmers practicing intercropping. This contradicts, however, studies from *central* Malawi: a study in the late 1990's found that only 30% of the maize crops in central Malawi were found to be intercropped (Scott and Maideni 1998) – the same area where Snapp, Rohrback et al. (2002) conducted research and concluded that farmers in Malawi do not generally intercrop.

5.2 Challenges of Intercropping

In Africa, the denigration of traditional agricultural practices like intercropping (which has been variously described as 'backwards' and 'primitive') has a long history. For example, Leakey (1936) quotes a Kenyan government official as stating '*the natives of the Kikuyu reserve have a wonderfully rich country, and if they could only be persuaded to cultivate scientifically, they could more than double their output*'. In Zimbabwe, researchers have claimed that traditional farming methods which incorporated both minimum tillage and mixed cropping were completely wiped out and replaced with a highly technical western farming system based on plough cultivation and continuous monocultures of commodity crops, and that the rationale for this was more evangelical than scientific (Page and Page 1991). During Africa's independence period, there were very few national agricultural scientists, and to fill this gap an entire generation of scientists were subsequently trained in European and American Universities. These researchers in many cases would then develop and lead national agricultural training centres based on western systems of agricultural management. This led, at least in part, to a situation in the early 1970's where '*little serious research has gone into intercropping systems, because such systems are associated with subsistence farmers and therefore not deemed worthy of being a topic of serious research endeavour*' (Norman 1974). At the same time, it should also be noted that scientific studies into intercropping – particularly traditional systems which are based on complex polycultures with different planting and timing requirements – is difficult to fit into western scientific studies which are often based on reductionist methodologies and 3-5 year project cycles.

The rise of neoliberal policies and the emergence of the environmental and participation movements began to change all this (Sumberg 2017). This growing concern with the environmental and health impacts of modern agriculture coincided with an increase in traditional technologies like intercropping in the 1970's (Horwith 1985), which has continued to today. A database search in Web of Science (all databases) found the following trend in numbers of scientific research articles relating to intercropping (see Figure 5.1 below).

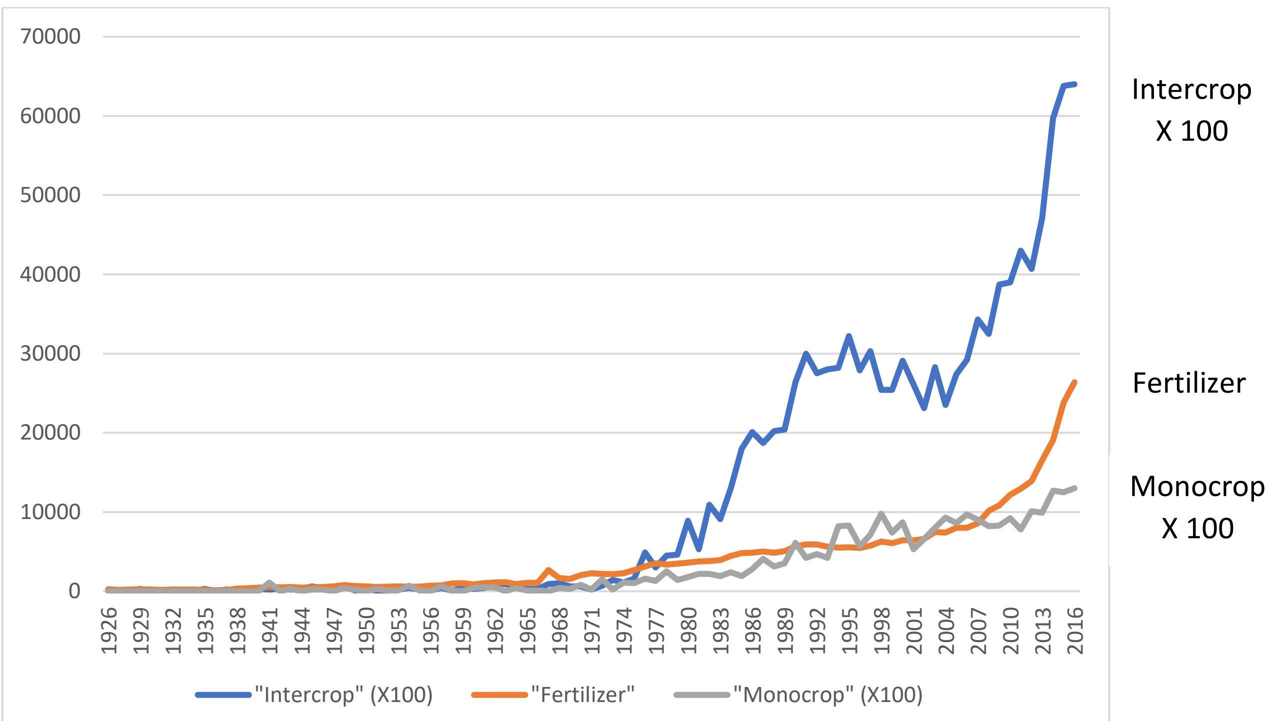

Figure 5.1: Results from Web of Science data search for the term 'Intercrop', August 4 2017. Results for the search terms 'Fertilizer' and 'Monocrop' are included for comparison purposes. Search terms 'Intercrop' and 'Monocrop' have been multiplied by 100 to fit on the same scale as 'Fertilizer'.

While there may be a growing interest in intercropping among researchers, there is relatively little impact to date on the ground. For example, while in Malawi 80% of farm families have one or more fields with a maize/bean intercrop, cultivar development (for legumes) has emphasized performance as a sole crop and fertilizer recommendations generally target sole-cropped maize (Snapp et al. 1998).

Agricultural policy is one of the biggest reasons intercropping has received relatively little research and developmental support in Africa. A production oriented approach to agriculture (and specifically the production of cereals) has dominated the policy discourse in Africa over the last few decades. While there is some scientific evidence that monocropping may be more financially advantageous for smallholder farmers than mixed cropping (c.f. (Manu et al. 1994; Waddington et al. 2007)), the bulk of the research from sub-Saharan Africa points to substantial benefits of intercropping for smallholder farmers. Keeping in mind that all agronomy is local and no one solution exists for all of Africa (Sumberg 2017), the continued push for monocropping agriculture throughout much of Africa seems to be more philosophical than scientific. This is in part based on the theory that industrialized, mechanized agriculture is the inevitable and proper path of development (intercropping is not easily compatible with mechanized agriculture); a desire to replicate the success of the green revolution in Asia, which trebled yields through the intensification of monocultures (Snapp et al. 2010); and a belief that the central challenge is to get the science and technology right, and all the messy and uncomfortable truths about institutions, politics and power can be ignored (Sumberg 2017).

This has led to situations like in Malawi, where the government has spent the bulk of its agricultural budget on a subsidized fertilizer and hybrid maize program in an attempt to have the country become self-sufficient in maize production. Whereas some NGO's and government programs now promote intercrops, many do not, including many organizations promoting conservation agriculture. For example, the Farming God's Way manual states '*Mixed cropping is a common African practise, especially with beans between maize rows, however neither of these crops reach their yield potentials with this system. We do not encourage a mixed cropping practise for manageability and best crop performance reasons*' (Dryden 2009).

A focus on monocropping is also partly related to markets. Modern agriculture has shifted the emphasis to a more market-related economy and this has tended to favour intensive monocropping systems (Horwith, 1985). A challenge with growing legumes for many of CFGB's partners in sub-Saharan Africa is knowing what to do with them, as access to markets in many cases is limited. This echoes a study in Malawi which found that intercrop is diversity linked to commercialization, with the share of land planted to maize intercrops rising among households with closer access to markets (Shaxson and Tauer 1992).

Gender is another reason why interest in intercropping (particularly intercropping with legumes) has lagged behind other technology options. Throughout much of sub-Saharan Africa, dried beans were a women's crop, a women's trade commodity, and pre-eminently a women's food (Robertson 1997). It is only relatively recently that the importance of women in agricultural food production and particularly food security has been emphasized instead of ignored, and much knowledge about traditional varieties and ways of growing legumes have been lost.

5.3 Improving Agricultural Systems in Sub-Saharan Africa

Population pressure, climate change, and growing levels of soil degradation all point to the inescapable fact that the agricultural status quo in Africa needs to change. Forty percent of farming households in sub-Saharan Africa are currently unable to achieve food self-sufficiency, and even those that do are often dependent on off-farm income (Frelat et al. 2016). Current models of agricultural intensification are not sustainable from an ecological or social point of view (Tittonell 2014) and solutions that have worked elsewhere and continue to be tried across Africa – for example the simple provision of adequate levels of fertilizer and improved seeds – are often not effective on many of Africa’s degraded soils (Nezomba et al. 2015).

The integration of legumes as intercrops and the promotion of conservation agriculture have both been promoted as potential solutions to some of the above challenges. Present research has given some hints that integrating both technologies together may help achieve more sustainable, productive and profitable, equitable, and resilient farming systems within sub-Saharan Africa. For smallholder CA farmers in Zimbabwe, where mulch is a generally a limiting factor in their CA farming system, I found that for the specific year of this study, and assuming the goal of these farmers was to maximize maize production, adding a legume intercrop reduced but did not eliminate the need to add supplemental mulch. The addition of a leguminous intercrop did have other benefits as well: increasing the economic profitability and food security impacts of the farming system (an effect that was more pronounced at the drier site) and increasing the total amount of biomass produced at the higher rainfall sites. Perhaps most significantly, adding a cowpea intercrop increased the food security benefits for farmers at all three study sites, but comparatively more at the drier site, indicating potential resilience benefits for farmers facing increased levels of drought under climate change.

While this research does provide some preliminary support for the integration of intercropping into CA systems, the variability of results and the different experiences of the farmers also suggests that intercropping legumes in CA systems is not ‘the’ sole answer to agricultural development in sub-Saharan Africa. With that in mind, I would like to suggest some areas for future work; first what specific research questions to look at, and secondly how to best answer these research questions.

5.2.1 Future Research: What

Intercropping Principles: Even a simple listing of the various options possible for a simple cereal-legume intercrop leads to so many potential solutions it is not impossible to scientifically evaluate them all: [Cereal species] X [Legume species] X [When to plant the legume species] X [Spacing] X [Row placement] X [Fertilizer options] X [Soil type] X [Season] X [Projected rainfall] X [etc.]. When combined with ongoing changes in biophysical environments, market conditions, farmer preferences and labour availability, etc. it is clear that what is needed is not a few more Norman Borlaugs, but millions of Norman (and Nancy) Borlaugs, who are armed with the principles and understanding needed to continuously experiment, innovate, and design their own site-specific farming solutions. While testing and adapting potential solutions to their own specific needs and contexts may be the job of individual farmers, a valuable role of scientific researchers may be to develop a set of basic principles to help farmers determine whether or not to intercrop, and if so to guide them in their initial choice of variables such as crop species, planting methods, and soil fertility management.

Long and short-term soil fertility management in intercropping systems: Despite the fact that intercropping of legumes has been identified as a promising alternative to the general lack of affordable soil improvement options in sub-Saharan Africa (Sileshi et al. 2008), and that fertilizer efficiency can be enhanced through diversification with legumes (Snapp et al. 2010), legume cultivar development has emphasized performance as a sole crop; and fertilizer recommendations generally target sole-cropped maize (Snapp et al. 1998). In part because of this, nutrient management remains the bottleneck for the expansion of ecologically intensive agriculture (Tittonell 2014).

Poly-cultural Systems: While poly-cultural agricultural systems are traditional in many areas of Africa, the vast majority of research I have seen on intercropping systems focuses on bi-cultural systems (most often, a cereal with a legume). The long-term traditional use of these systems, coupled with the few research results that do look at alternatives to simple cereal-legume intercrops point to some interesting possibilities. For example, results from Snapp's work on doubled-up legume systems in Malawi (Snapp 2017) found that when lablab and cowpea are intercropped, cowpea growth begins to decline at the same time (around 3 months after planting) lablab growth starts to accelerate; and that indeterminate, long-duration legumes (such as lablab) have been found to produce profits, protect the soil, and produce resources of mulch and nitrogen fertilizer if allowed to grow perennially in fields (Snapp and Silim 2002).

Longer-term, field level applications: While the results of this research point to some interesting possibilities for smallholder farmers, it's applicability is limited due to the short duration and small size of the research plots. Much more interesting and useful data would come from field level implementation of these technologies, and following implementation over a long enough time frame to begin to understand impacts on variables such as economics, biodiversity, and soil organic carbon (SOC).

5.2.2 Future Research: How

Sustainably and equitably feeding the world over the next century is one of the biggest challenges facing the human species, and like other pressing concerns such as climate change is an example of a wicked problem. Wicked problems are symptomatic of complex situations and have a number of defining characteristics. These include: a high level of uncertainty about how to produce desired results and great disagreement among diverse stakeholders about the nature of the problem and what, if anything, to do; a one-of-a-kind uniqueness as results are highly dependent on initial conditions and depend on a number of factors of which there is little advance knowledge; not solvable, but only manageable as there is no clearly defined solution space and attempts to address wicked problems almost always cause other problems which need to also be addressed; and finally no 'right' answer and many possible solutions (Rittel and Webber 1973; Buchanan 1992; Camillus 2008; Ireland et al. 2012; Farrell and Hooker 2013; Xiang 2013; Zivkovic 2015).

Engage with numerous stakeholders, disciplines, and differing viewpoints: Acknowledging that we are working with a wicked problem when dealing with the challenge of how to improve smallholder agricultural systems forces us to a number of (sometimes uncomfortable) truths. Firstly, it changes the role that we, as scientists, envision for ourselves: from the designer/creator of solutions that are disseminated out and applied, to the more modest role of a contributor to ongoing negotiation processes among stakeholders (Giller et al. 2008). I would tend to agree with Sumberg (2017), who argues that '*rather than isolating ourselves by focusing on (universal) technical solutions, agronomists need to embrace agronomy as a situated, place-based science, and to do this they must engage more openly with the other agricultural and social disciplines'*. I would add to Sumberg's comment that not only is it necessary to engage with more disciplines, it is also critical to engage with other local actors (government extension officers, businesses, NGO's, etc.) and particularly to more actively engage with local farmers. Secondly, acknowledging that we are working with a wicked problem forces us to accept there is no one 'right' solution. Scientific arguments, for example, about whether CA is '*the best hope of increasing food production rapidly, at low cost and without adverse environmental consequences in developing countries'* (Kassam and Brammer 2013); whether it will '*only deliver the productivity gains that are required to achieve food security and poverty targets if farmers have access to fertilizers and herbicides'* (Gowing and Palmer 2008), or whether it is just a '*watered-down version'* of the more transformative agroecology that is really needed (Moeller and Pimbert 2018) become moot points when one realizes that all of these are possible solutions, and which solution to choose is dependent on the local context, including the various viewpoints of the main actors within that context. Put another way, the choice of which legume(s) to plant as an intercrop includes numerous technical factors such as agricultural potential, rainfall patterns, and soil type (Erenstein 2003; Sileshi et al. 2008; Mupangwa and Thierfelder 2014; Ewansiha et al. 2015;

Temesgen et al. 2015). However, the choice of which legume(s) to plant as an intercrop also needs to include socio-economic factors such as the farmer's ability to manage risk, their food preferences, and their livelihood strategy (Snapp et al. 2002; Amede and Kirkby 2004; Thierfelder et al. 2012b; Vanlauwe et al. 2014; Leonardo et al. 2015; Temesgen et al. 2015; Ewansiha et al. 2016). Potential solutions need to take into account all of these factors (both technical and socioeconomic) and answered on a case by case basis (Giller et al. 2011a).

Shift the focus from tons per hectare to sustainable, productive and profitable, equitable and resilient farming systems: Although there are many positive reports on the production impacts of intercropping and of CA from across Africa, there has also been much disappointment among researchers and development practitioners over low adoption rates of both technologies. Issues such as labour, markets, world-view and mindsets, competing priorities, and lack of knowledge have all been postulated as reasons for low adoption rates (Snapp et al. 2002; Dryden 2009; Giller et al. 2009). It is clear that yield per hectare is not the only factor that farmers take into consideration when choosing what and how to plant, and yet increased yields from a purely technological standpoint remains one of the major issues driving agricultural research and development (Rockström et al. 2017). While technological innovation is necessary, it is not sufficient. For example, while the technology for successful CA has been in place for decades, it took more than fifty years for the enabling environment and other processes for CA uptake (i.e. mechanical innovation, agricultural knowledge, manufacturing scale, on farm capital, changes in output and input market prices, etc.) to develop (Brown et al. 2017).

From research stations to participatory, place-based research: What is the right thing for a farmer to do one year may not be the right thing in a different year, let al.one for a different farmer at a different location. This fine-scale variation in social, economic and ecological contexts creates a strong need for local adaptation (Coe et al. 2014), and this adaptation needs to be based on a thorough and interdisciplinary understanding of the local situation before developing potential solutions (Giller et al. 2011b). Traditional styles of agricultural research and agrotechnology transfer may poorly suit the development of technology-based approaches to crop production unless complemented with effective farmer participation and whole-systems analysis going beyond mere technology substitution (Rockström et al. 2017). Farmer knowledge of soil quality and other biophysical elements has been shown to be highly detailed and complex (Pauli et al. 2012), and existing small-scale farming technologies often have high water, nutrient and energy use efficiencies and conserve biodiversity conserve resources without sacrificing yield (Kiers et al. 2008). The growing trend to include such knowledge in research and development programs is laudable, but the techniques used – often a quick gathering of information from questionnaires or focus groups at the beginning of a project - cannot substitute for longer cooperation in experimentation between farmers and researchers (Giller and Cadisch 1995). To be successful any change strategy needs to be adapted to the particular situation of a farm, achieved through a learning process with the farmers and technical advisers as main participants (Dogliotti et al. 2014).

Within this project, we were surprised by the enthusiasm and interest showed by the participating farmers involved in the project, as well as by other members of the community who became more interested in the experiments as the season progressed. Farmers were empowered through managing and learning from an experiment on their farm. Many farmers referred to the experiment as their "classroom" where they were able to observe the growth of new legumes (lablab and pigeon pea) and compare the differences between the treatments. For the majority of the farmers, each visit by the technician became a learning opportunity that stimulated new ideas and resulted in knowledge creation which we believe will enhance innovation.

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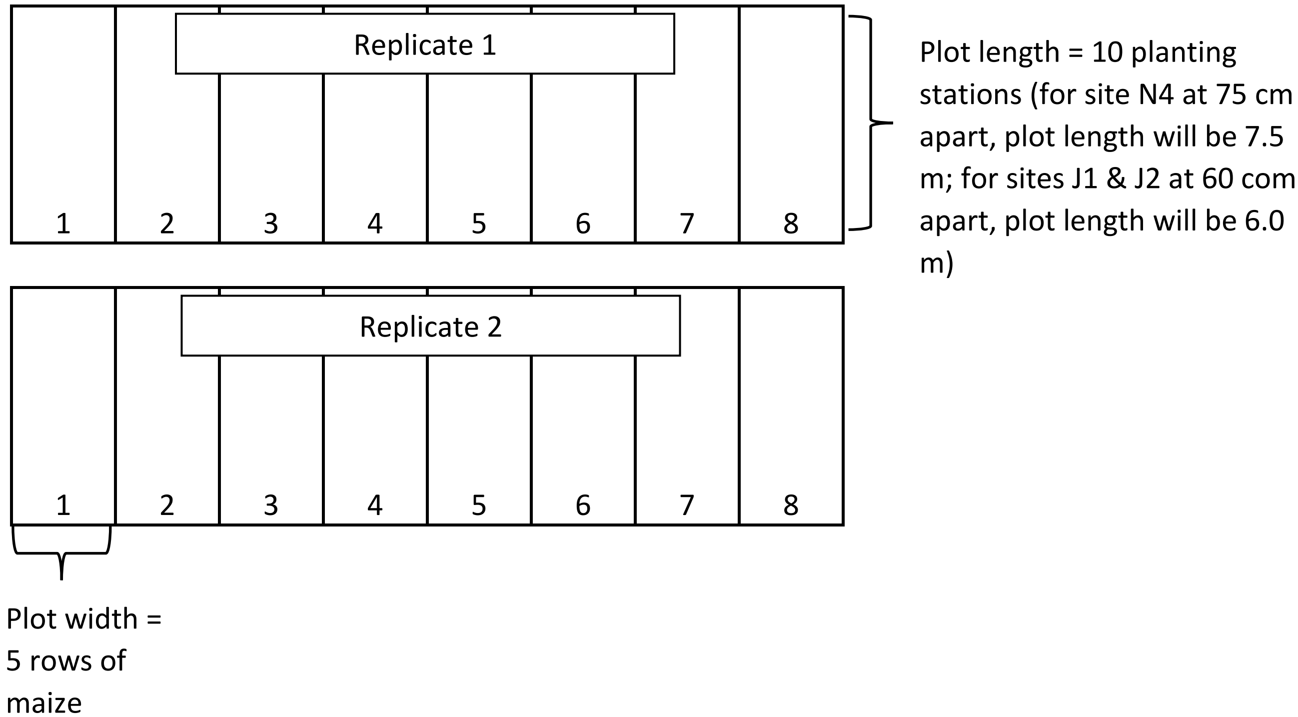
Appendix A: Experimental Design Information Sheet

Plot configuration:



t: 1) Mulched maize monocrop
2) Mulched maize intercropped with cowpea
3) Mulched maize intercropped with lablab
4) Mulched maize intercropped with pigeon pea
5) Maize monocrop – no mulch applied
6) Maize intercropped with cowpea – no mulch applied
7) Maize intercropped with lablab – no mulch applied
8) Maize intercropped with pigeon pea – no mulch applied

Total area required for 16 plots = 40 rows of maize x 20 planting stations deep (approximately 36 m x 15 m, if maize rows are 75 cm apart and planting stations are 75 cm apart)

Appendix B

Economic Calculations

Un-Mulched Plots												
		Maize Yield	SE	Land Size	Seed Used	Net Benefit from Maize[1]	Cowpea Yield	SE	Land Size	Seed Used	Net Benefit from Cowpea[2]	Total Benefit[3]
		Kg ha^{-1}		ha	kg	USD	Kg ha^{-1}		ha	kg	USD	USD
Intercropped	J1	5722	574	0.5	9.4	$ 1,140.64	407	148	0.5	15.0	$ 150.80	$ 1,291.44
	J2	5241	1019	0.5	9.4	$ 1,044.44	1000	37	0.5	15.0	$ 388.00	$ 1,432.44
	N4	4160	889	0.5	9.0	$ 828.40	2200	244	0.5	15.0	$ 868.00	$ 1,696.40
Monocropped	J1	4426	1241	0.5	9.4	$ 881.44						$ 881.44
	J2	3389	981	0.5	9.4	$ 674.04						$ 674.04
	N4	4142	444	0.5	9.0	$ 824.80						$ 824.80
Mulched Plots												
		Maize Yield	SE	Land Size	Seed Used	Net Benefit from Maize[1]	Cowpea	SE	Land Size	Seed Used	Net Benefit from Cowpea[2]	Total Benefit[3]
		Kg ha^{-1}		ha	kg	USD	Kg ha^{-1}		ha	kg	USD	USD
Intercropped	J1	9130	93	0.5	9.4	$1,822.24	907.4	315	0.5	15	$ 350.96	$ 2,173.20
	J2	5593	481	0.5	9.4	$1,114.84	1296.3	111	0.5	15	$ 506.52	$ 1,621.36
	N4	3876	462	0.5	9.0	$771.60	2155.5	67	0.5	15	$ 850.20	$ 1,621.80
Monocropped	J1	6722	1130	0.5	9.4	$1,340.64						$ 1,340.64
	J2	7037	74	0.5	9.4	$1,403.64						$ 1,403.64
	N4	3964	516	0.5	9.0	$789.20						$ 789.20

1. Net Benefit from Maize = (([Maize Yield (kg ha^{-1})] * [Land Size (ha)]) – [Maize Seed Used]) * 0.40 kg^{-1}

2. Net Benefit from Cowpea = (([Cowpea Yield (kg ha^{-1})] * [Land Size (ha)]) – [Cowpea Seed Used]) * 0.80 kg^{-1}

3. Total Benefit = Net Benefit from Maize + Net Benefit from Cowpea

Nutrition Calculations

Plot	Maize Yield	Land Size	Seed Req.	Food Req.	Maize Income[1]	Cowpea Yield	Land Size	Seed Req.	Food Req.	Cowpea Income[2]	Cost of Oil	Cost of Salt	Total Net Benefit[3]
Un-Mulched – 0.5 ha plot													
	Kg ha^{-1}	ha	kg	kg	USD	Kg ha^{-1}	ha	kg	kg	USD	USD	USD	USD
J1	5722	0.5	9.4	1000	$740.64	407	0.5	15	200	-$9.20	$90.00	$ 5.00	$ 636.44
J2	5241	0.5	9.4	1000	$644.44	1000	0.5	15	200	$228.00	$90.00	$ 5.00	$ 777.44
N4	4160	0.5	9.0	1000	$428.40	2200	0.5	15	200	$708.00	$90.00	$ 5.00	$ 1,041.40
J1	4426	0.5	9.4	1000	$481.44				200	-$160.00	$90.00	$ 5.00	$ 226.44
J2	3389	0.5	9.4	1000	$274.04				200	-$160.00	$90.00	$ 5.00	$ 19.04
N4	4142	0.5	9.0	1000	$424.80				200	-$160.00	$90.00	$ 00	$ 169.80
Mulched – 0.5 ha plot													
J1	9130	0.5	9.4	1000	$1,422.24	907.4	0.5	15	200	$190.96	$90.00	$ 5.00	$ 1,518.20
J2	5593	0.5	9.4	1000	$714.84	1296.3	0.5	15	200	$346.52	$90.00	$ 5.00	$ 966.36
N4	3876	0.5	9	1000	$371.60	2155.5	0.5	15	200	$690.20	$90.00	$ 5.00	$ 966.80
J1	6722	0.5	9.4	1000	$940.64				200	-$160.00	$90.00	$ 5.00	$ 685.64
J2	7037	0.5	9.4	1000	$1,003.64				200	-$160.00	$90.00	$ 5.00	$ 748.64
N4	3964	0.5	9	1000	$389.20				200	-$160.00	$90.00	$ 5.00	$ 134.20
Un-Mulched – 0.25 ha plot													
J1	5722	0.25	4.7	1000	$170.32	407	0.25	7.5	200	-$84.60	$90.00	$ 5.00	$ (9.28)
J2	5241	0.25	4.7	1000	$122.22	1000	0.25	7.5	200	$34.00	$90.00	$ 5.00	$ 61.22
N4	4160	0.25	4.5	1000	$14.20	2200	0.25	7.5	200	$274.00	$90.00	$ 5.00	$ 193.20
J1	4426	0.25	4.7	1000	$40.72				200	-$160.00	$90.00	$ 5.00	$ (214.28)
J2	3389	0.25	4.7	1000	-$62.98				200	-$160.00	$90.00	$ 5.00	$ (317.98)
N4	4142	0.25	4.5	1000	$12.40				200	-$160.00	$90.00	$ 5.00	$ (242.60)
Mulched – 0.25 ha plot													
J1	9130	0.25	4.7	1000	$511.12	907.4	0.25	7.5	200	$15.48	$90.00	$ 5.00	$ 431.60
J2	5593	0.25	4.7	1000	$157.42	1296.3	0.25	7.5	200	$93.26	$90.00	$ 5.00	$ 155.68
N4	3876	0.25	4.5	1000	-$14.20	2155.5	0.25	7.5	200	$265.10	$90.00	$ 5.00	$ 155.90
J1	6722	0.25	4.7	1000	$270.32				200	-$160.00	$90.00	$ 5.00	$ 15.32

J2	7037	0.25	4.7	1000	$301.82				200	-$160.00	$90.00	$ 5.00	$ 46.82
N4	3964	0.25	4.5	1000	-$5.40				200	-$160.00	$90.00	$ 5.00	$ (260.40)

1. Net Maize Income = (([Maize yield kg ha^{-1}]*[Plot size ha])-([Seed Requirements kg]+[Food Requirements])) * 0.40 USD kg^{-1}

2. Net Cowpea Income = (([Cowpea yield kg ha^{-1}]*[Plot size ha])-([Seed Requirements kg]+[Food Requirements])) * 0.80 USD kg^{-1}

3. Total Net Benefit = [Maize income] + [Cowpea income]