Productivity of Maize-Legume Intercropping under No-till in central Mozambique: Challenges and Opportunities

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Abstract
The multi-purpose uses of crop harvest residues in mixed crop-livestock systems make mulch based cropping less feasible. Legume intercrops are an alternative and feasible soil surface cover strategy that smallholder farmers can readily utilize. Legume intercrops are important in farming systems because they can ensure food security, increase income, reduce soil erosion, suppress weeds and fix N resulting in increased efficiency of land use through more complete utilization of solar radiation, water and nutrients. This paper seeks to evaluate the productivity of maize-grain legume intercropping as an alternative to sole cropping especially in mixed crop-livestock systems where harvest/cereal crop residues are fed to livestock and thus are not available for mulch. We evaluated two intercropping strategies practiced by farmers in central Mozambique, over two seasons, i.e. alternate row intercrops and within-row intercrops for both maize/pigeonpea and maize/cowpea. The advantage of maize/pigeonpea intercrops is that in successive years a ratoon crop of pigeonpea can be grown reducing investment costs of seed and providing erosion control early in the season when much of the field surface will be uncovered. The within-row intercrops were more productive with land equivalent ratios (LER) of between 1.2 and 1.6, compared with alternate row intercrops with LER values ranging between 1.05 and 1.40 for the two seasons. Although less productive, the alternate row intercrops had a greater potential of providing surface cover between the rows of the main crop. Results in 2009/10 growing season clearly showed that intercropping pigeonpea and maize, and maize and cowpea reduced the risk of total crop failure. Pigeonpea was able to withstand the long season dry spell which lasted for at least 55 days but was followed by excessive rainfall. The relay/intercropped planted cowpea had high yields after a total crop failure by maize. Discussions with farmers clearly showed that the drivers of intercropping were income generation and food security. Farmers had previously established strong market linkages for pigeonpea, and cowpea was considered a very important crop for food. Challenges include the late maturity of pigeonpea which coincides with free roaming livestock but farmers have responded by targeting pigeonpea to fields close to their homesteads. However, they still need access to early maturity cultivars to completely overcome this challenge. On average, intercropping increased weeding time by 36% compared to sole crops for all the weeding times. Farmers mentioned the need to take extra care in the intercrops especially the first weeding as pigeonpea grows slowly and will be hardly visible. In the third weeding, if pigeonpea is between rows of maize, it impedes the smooth use of hand hoe or movement along the rows. Despite these challenges, results show that smallholder agriculture can be improved significantly through inclusion of grain legume intercrops. We therefore conclude that maize-legume intercropping combined with reduced tillage reduces the risk of crop failure, improves productivity per unit area and ensures food security in vulnerable production systems.

Keywords: maize-legume intercropping, no-till, productivity, challenges, opportunities

Introduction

Smallholder agriculture in southern Africa is often characterized by mixed crop-livestock systems (Thornton and Herrero, 2001) in which intensive soil tillage and feeding of crop harvest residues to livestock are common practices (Lal, 1991; Erenstein, 2002; Rao and Hall, 2003). Livestock support crop production through the provision of draught power and manure, is important for food and income provision as well as being a key asset in times of scarcity (Stroebel et al., 2008). The sustenance of livestock is therefore critical to the farm and the option to feed crop residues is undoubtedly the best available in the dry season. The low productivity of maize of around 1.3 t ha^{-1} (Banziger and Diallo, 2001) coupled with the uses of crop harvest residues for livestock feed as well as their consumption by termites (Ellis-Jones and Whitmore, 2004; Nhamo et al., 2007) makes mulch-based cropping in the sub-humid and semi-arid regions of southern Africa less feasible (Unger et al., 1991; Giller et al., 2009). Practical and feasible options to provide soil cover during the production of the main crop are desirable. On the other hand, the needs for effective weed control and provision of good seed germination medium have often been cited as reasons for tillage (Unger, 1984; Kuipers, 1991). However, no-tillage systems of cultivation combined with soil cover potentially conserves water, reduces soil erosion, maintains more organic matter and may be economically beneficial to the farm (Lal, 1995; Erenstein, 2003; Erenstein et al., 2008).

Alternative strategies for soil cover exist in the form of living mulches such as grain legume intercrops (Hartwig and Ammon, 2002). Intercropping is the only feasible option to grow two or more crops per year because much of southern Africa is characterized by a unimodal rainfall pattern (Taljaard, 1986) that is only suitable for a single cropping season per year. In intercropping, two or more crops are grown simultaneously on the same area of land with the possibility of a greater total yield than would be obtained from either sole crops (Willey, 1979; Seran and Brintha, 2010). Grain legume intercrops are preferred because besides providing soil cover between the rows of the main crop, they are potential sources of plant nutrients that compliment or supplement inorganic fertilisers and ensure food security. Legume intercrops are included in cropping systems due to their ability to reduce soil erosion (Giller and Cadisch, 1995), suppress weeds and fix biological N (Giller et al., 1994), add soil organic matter (Hartwig and Hoffman, 1975), reduce pests and diseases (van der Pol, 1992; Trenbath, 1993), spread labour needs (van der Pol, 1992) and can maintain productivity on the land for many years. Efficiency of land use is enhanced through more complete utilization of solar radiation (Keating and Carberry, 1993), water (Morris and Garrity, 1993a) and nutrients (Morris and Garrity, 1993b).

The most common companion crops for intercropping with cereals are groundnut (*Arachis hypogaea*), cowpea (*Vigna Unguiculata* L. Walp), soybean (*Glycine max* [L] Merr), common bean (*Phaseolus Vulgaris*) and perennial legumes such as pigeonpea (*Cajanus cajan* (L) Millsp.) (MacColl, 1989; Mafongoya, 2006). These legumes are important because of N_2-fixation reducing the reliance of external N sources of fertiliser (Giller et al., 1994) Crops such as pigeonpea are deep rooted and have the ability to extract nutrients from deeper soil horizons that are not available for the cereal crop complementing nutrients derived from leaf fall and litter decomposition (Mekonnen et al., 1997). Pigeonpea is also a perennial crop thus it can be maintained from year to year as a ratoon crop without the need for seeding and the succeeding main crop is planted into the suppressed cover crop using minimum tillage (Hartwig and Ammon, 2002). The selection of cover crop species suitable for crop rotation, climate, and specific desirable objectives is important for integration into diverse farming systems (Vollmer et al., 2010).

The promotion of no-till in southern Africa is underway (Derpsch, 2005; Mupangwa et al., 2007; Wall, 2007) and shows promise in some situations but not in others (Giller et al., 2009). No-tillage provides a pathway for reduction of costs especially those related to tillage (Aigner et al., 2003; Bowman et al., 2005). However, the success of no-tillage systems is strongly related to the availability of adequate amount of residue mulch on the soil surface (Lal, 1986) as well as crop rotation for weed and disease control and high inputs particularly N fertiliser (Peigné et al., 2007; Vollmer et al., 2010). Thus the inclusion of grain legumes crops combined with no-tillage potentially improves soil chemical and physical characteristics, and farm level benefits such as low cost and reduced risk of crop failure in the long term (Machado and Silva, 2001). Despite being experimentally successful, no-tillage adoption by farmers is often hampered by the high costs of herbicides, unavailability of no-till planting machines and unavailability of seeds of cover crops and feasibility of mulch management (Machado and Silva, 2001). We hypothesize that, combined with an appropriate cropping system with legume intercrops; no-tillage does promote conservation of soil moisture, improves soil organic matter and ensures higher yields.

The involvement of farmers in the research process enabled us to identify the key components as well as entry points that can allow us to improve the maize-legume intercrop systems and make it fit within the farmers' circumstances (Figure 1). Farmers in central Mozambique are practicing maize-pigeonpea intercropping planted in distinct rows as well as maize-cowpea intercropping but planted in a non-systematic pattern. Research experiences as well as farmer practices in southern Malawi (Sakala, 1994; Sakala et al., 2000) where intercropping long-duration pigeonpea varieties with normal farmers' maize plant population led to little grain yield loss for the associated maize crop. Farmers in these sites clearly face constraints regarding labour availability, access to improved seed and fertiliser. They can only afford very little quantities of fertiliser ca. 10 kg compound fertiliser per household and this fertiliser is preferentially allocated to vegetable gardens where high returns from tomatoes are assured. It is clear from Figure 1 that with the same inputs, we can manipulate the intercrop strategy by trying various arrangements of the same or different crops to achieve the desired objectives of food security and cash income. For this reason we experimented with farmers the intercrop options practiced in southern Malawi and those practiced in central Mozambique. Our evaluation of the intercrop options to increase productivity was primarily focused on the immediate benefits such as food security and cash income for the farmer as these are likely to define the adoption of new technologies.

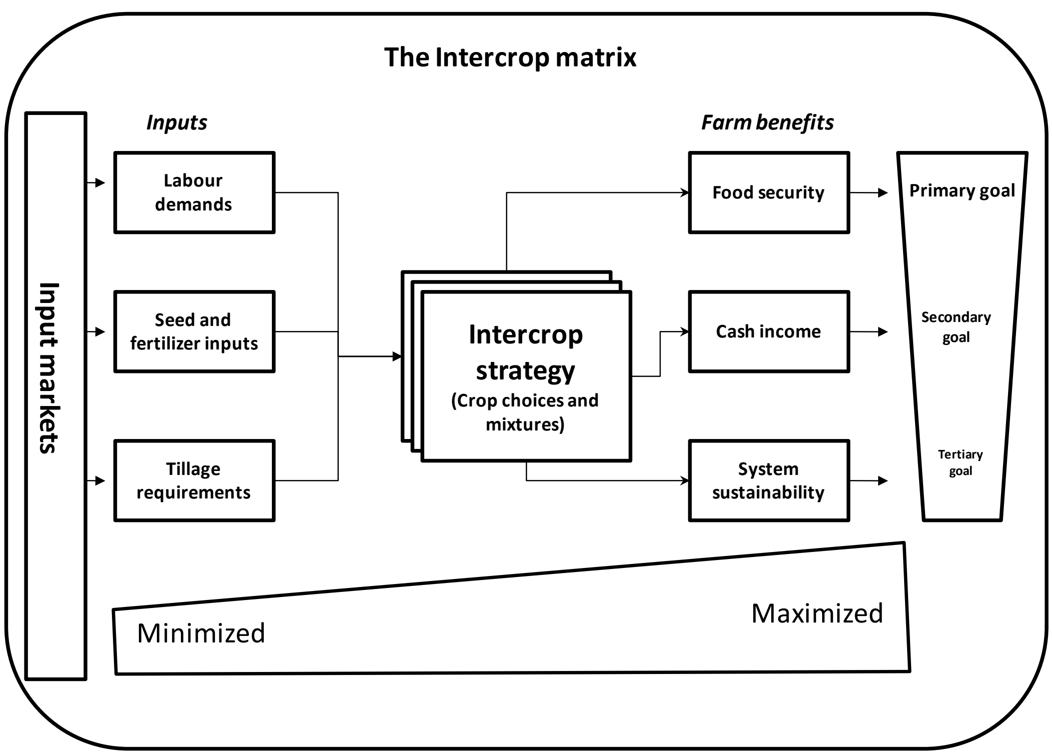

Figure 1. The intercrop matrix showing the important components as well as key entry points to improve the intercrop system. Discussions with farmers clearly showed that the primary goal of any technology will be to ensure food security followed by cash income and lastly and in most cases they do not mention soil productivity. We hypothesize that in intercrop systems when perennial crops like pigeonpea are involved, tillage requirements will be reduced with time as a ratoon crop of pigeonpea can be used for 3-4 years. The use of ratoon crop will reduce the need for seed, addition of good quality leaves will reduce the need for N fertiliser, and the suppression of weeds in the intercrop will result in decline in total labour requirements. The minimization of costs on the left side will automatically lead to maximization of benefits on the right hand side.

The specific objectives of the study were (a) to evaluate the productivity of maize-grain legume intercropping as an alternative to sole cropping especially in mixed crop-livestock systems where harvest/cereal crop residues are fed to livestock and thus are not available for mulch, and (b) to understand the circumstances that lead to the success of maize-legume intercropping under no-till, and to identify challenges and opportunities for improved impact.

Materials and Methods

The maize-legume intercropping experiments were established in Manica and Gorongosa districts central Mozambique (Figure 2).

Figure 2. The location of the study sites in Manica and Gorongosa districts, central Mozambique.

Ruaca village, Manica

A maize-pigeonpea intercrop experiment was established in 2008/09 and 2009/10 in Ruaca village (S 18°50', E 33°11') in Manica, central Mozambique. The site has an altitude of 700 m and receives rainfall of between 800 and 1000 mm annually. Soils from the experimental fields were of low fertility with clay content ranges of between 6 and 15%, silt 2-12% and sand 74-90% classified as Oxisols (Maria and Yost, 2006). The farming system is the mixed-crop livestock system, with cattle being the most important livestock type. Extensification characterized by slash and burn and no use of chemical fertilisers for crop production are the most notable features of the farming system. Pigeonpea is an important cash crop and is mostly intercropped with maize. The experimental fields were previously under continuous monocropping of maize with conventional mouldboard ploughing to a depth of about 20 centimeters. The fertilisation strategy for the experiment was to provide the legume with non-limiting P conditions and then evaluate maize response to N fertilisation. The following treatments were established under minimum no-tillage:

- Maize sole crop was planted at a spacing of 0.9 m between rows and 0.3 m within rows,
- Pigeonpea sole crop was planted at a spacing of 1.0 m between rows and 0.5 m within rows.
- The "*in-row intercropping*" treatment had maize and pigeonpea interplanted within the same row (0.9 m between rows and 0.45 m between maize and pigeonpea plants within the row, three plants per station),
- The "*2:1 intercropping*" treatment had two maize rows alternated with a single row of pigeonpea (2 m between rows of pigeonpea and 0.9 m between rows of maize).

Fertiliser treatments were: (i) control, (b) 20 kg P ha^{-1}, (c) 20 kg P ha^{-1} + 30 kg N ha^{-1}, and (d) 20 kg P ha^{-1}+ 60 kg N ha^{-1}. Planting stations as well as all weeding operations were accomplished using hand hoes.

Nhanguo village, Gorongosa

A relay planted maize-cowpea intercrop experiment was established in 2008/09 and 2009/10 in Nhanguo village (S18°46', E34°20') in Gorongosa district, central Mozambique. The site has an altitude of 300 m and receives rainfall of between 600 and 800 mm annually. Soils are of extreme poor fertility due to many years of cultivation with no use of fertilisers. Soils from the experimental fields were of low fertility with clay content ranges of between 8-22%, silt 12-22; sand 60-80% and classified as Oxisols of low fertility (Maria and Yost, 2006). The farming system is mostly crop based with a few farmers owning goats and pigs but cattle are not part of the system. Extensification is also common, slash and burn is no longer practiced due to population increases. It is not uncommon to see crop fields on the very steep slopes (30% or more) of Gorongosa mountain. The hand hoe in combination with burning is commonly used for land preparation and weeding is also accomplished by hand hoe. The following treatments were established under no-tillage:

- Sole maize was planted at a spacing of 0.9 m between rows and 0.3 m within rows
- Sole cowpea at 0.45 m between rows and 0.2 m within rows.
- The "*in row intercropping*" treatment had maize and cowpea interplanted within the same row (0.9 m between rows and 0.3 m between maize and cowpea plants within the row),
- The "*1:1 intercropping*" treatment had one maize row alternated with a single row of cowpea row (0.9 m between rows of maize and cowpea in between).

Fertiliser treatments were: (i) control, (b) 20 kg P ha^{-1}, (c) 30 kg N ha^{-1}, 20 kg P ha^{-1}, and (d) 60 kg N ha^{-1}, 20 kg P ha^{-1}. Maize was planted 6 weeks earlier than cowpea in the relay intercrop. We also compared one local cowpea variety with the erect type IT18 variety. Planting stations as well as all weeding operations were accomplished using hand hoes.

Statistical analysis

Effects of important factors such as crop arrangement and fertiliser application on crop yield were analysed in a two-way ANOVA using SAS 9.2. Intercrop productivity was analysed using the land equivalency ratio (LER) method (De Wit and Van Den Bergh, 1965) . The LER is computed by dividing the intercrop grain yields (kg ha^{-1}) by the pure stand grain yields for each component crop in the intercrop, these two figures are then added together (Equation 1). Values of LER greater than 1 show an advantage while those less than 1 show a disadvantage of intercropping.

$$\text{LER} = \left[\frac{Intercrop\ maize\ (t\ ha^{-1})}{Sole\ maize\ (t\ ha^{-1})}\right] + \left[\frac{Intercrop\ legume\ (t\ ha^{-1})}{Sole\ legume\ (t\ ha^{-1})}\right] \qquad 1$$

Partial budget analysis

Partial budgeting is important for providing a measure of changes in income and returns to limited-resources (Boehlje and Eidman, 1984). The major variable costs were weeding and seed costs, during calculation we did not consider fertiliser costs as farmers currently do not use fertiliser for crop production. We therefore used yield results from the control treatments without fertilizer added to calculate income as well as the costs of weeding and seed. The marginal rate of return was calculated by expressing the difference between the net benefit of the treatments under comparison as a percentage of the difference of the total cost (Evans, 2005)

Farmer evaluation of maize-pigeonpea intercrops

An evaluation exercise was conducted to establish the acceptability of maize-pigeonpea intercrops using a combination of visual assessments, ranking and scoring procedures (Abeyasekera et al., 2002). The criteria for evaluation was developed and weighted through pair-wise ranking. A matrix scoring method on a scale of 1-20 was used to evaluate the different intercrop and sole crop treatments using the developed criteria. Final scores were obtained by multiplying the scores given by farmers and the appropriate weight of each criterion (Pimbert, 1991). Acceptability was calculated as the percentage of total score to the maximum possible score for each treatment.

Results

Maize - pigeonpea intercrop productivity

The intercrop treatments were at least equal to or more productive than the sole crop. The in row intercropping strategy was more productive than the farmers' two rows of pigeonpea alternating with a row of maize. Although pigeonpea yields were suppressed in 2009/10 compared to 2008/09, intercrop productivity was higher in 2009/10 (Table 1).

Table 1. Land equivalency ratios for maize-pigeonpea intercrops in 2008/09 and 2009/10 in Ruaca Mozambique.

	2008-2009 season		**2009-2010 season**	
Fertiliser treatment	In row intercrop	2:1 intercrop	In row intercrop	2:1 intercrop
Control	1.2	1.1	1.6	1.2
20 k P ha^{-1}	1.1	1.1	1.6	1.5
30 kg N + 20 kg P ha^{-1}	1.1	1.1	1.5	1.5
60 kg N + 20 kg P ha^{-1}	1.2	1.0	1.5	1.5
SEM	0.02		0.04	

Labour requirements for weeding maize–pigeonpea intercrops

Intercropping significantly increased the weeding time compared to sole crops for all the weeding times (Table 2). Farmers mentioned the need to take extra care in the intercrops especially the first weeding as pigeonpea grows slowly and is hardly visible, that takes more time compared to sole crop of maize. In the third weeding, they mention that if pigeonpea is between rows of maize, it impedes the smooth use of hand hoe or movement along the rows. On average, intercropping increased weeding time by 36%.

Table 2. Labour requirements (man days) as affected by maize and pigeon pea sole crops and intercrops in Ruaca for the 2009-10 season.

Treatment	**Weeding number**			**Total**
	1	2	3	
Sole maize	6.0	4.8	6.7	17.6
Sole pigeonpea	6.5	5.0	6.7	18.2
In row intercropping	8.2	6.2	7.9	22.3
2: 1 intercropping	9.1	7.8	9.6	26.4
SEM		0.4		

Maize-cowpea intercrop productivity

Maize-cowpea intercrops were highly productive despite the near total loss of the main crop (maize) in Gorongosa (Table 3). The poor productivity of maize meant that there was reduced competition to the companion cowpea crop thus the high LER values were driven more by cowpea productivity. Results show that staggered intercropping is a perfect strategy to reduce risk of total crop failure under rain-fed conditions. Maize yield data is based on data from only one farm where maize was harvested, the other 5 farms experienced total loss of maize due to the prolonged dry spells.

Table 3. Land equivalency ratios of maize-cowpea intercrops as affected by fertiliser treatments in 2009/10.

	Intercrop treatment	
Fertiliser treatment	In row intercrop	1:1 intercrop
Control	1.1	1.4
20 k P ha^{-1}	1.2	1.4
30 kg N + 20 kg P ha^{-1}	1.7	1.9
60 kg N + 20 kg P ha^{-1}	1.8	1.8
SEM	0.1	

Partial budget analysis

The analysis of benefits versus costs showed that legumes are much more profitable than maize, production of pigeonpea as a sole crop has a marginal rate of return over sole maize of 132% followed by in row intercropping at 115% and lastly 2:1 intercropping at 85% (Table 4). Results indicate that profitability is directly related to proportion of legume in the intercrop. Although the intercrop treatments had higher costs due to weeding, these costs were offset by the higher selling price of pigeonpea. The absence of opportunity cost for labour in these farming systems potentially increases the benefits associated with maize-pigeonpea intercropping.

Table 4. The benefits and costs of sole pigeonpea and maize-pigeonpea intercropping compared to sole maize cropping.

Item	Sole maize	Sole pigeonpea	In row intercropping	2: 1 intercropping
Cost of seeds (MT)	675	720	1395	1200
Cost of weeding (MT)	3168	3276	4014	4752
Total costs (MT)	3843	3996	5409	5952
Sales (MT)	10750	20000	20250	18750
Net Income (MT)	6907	16004	14841	12798
Net Income USD (1USD = 30MT)	230	533	495	427
Marginal rate of return (%)		**5946**	**507**	**180**

Farmer evaluation of maize-pigeonpea intercrops

Farmers identified food security, cash income, input costs, ease of weeding and time to maturity in that order as important consideration when evaluating maize-pigeonpea intercrops. The intercrops were much more preferred than sole crops; the in row intercropping strategy was found to be the most acceptable (84%) followed by 2:1 intercropping, and sole maize was more acceptable to farmers than sole pigeonpea (Table 5).

Table 5. Acceptability of maize-pigeonpea intercrops to farmers' production orientation and objectives in Ruaca village, numbers in parenthesis are the weighted scores (score x weight).

Evaluation criteria	Treatment (Scoring scale 1-20)			
	Sole maize	Sole pigeonpea	2: 1 intercrop	In row intercrop
Food security (weight =5)	14 (70)	8 (40)	19 (95)	20 (100)
Cash income (weight =4)	6 (24)	18 (72)	16 (64)	20 (80)
Input costs (weight =3)	15 (45)	9 (27)	12 (36)	10 (30)
Ease of mechanical weeding (weight =2)	15 (30)	14 (28)	6 (12)	15 (30)
Time to maturity (weight =1)	14 (14)	4 (4)	12 (12)	12 (12)
Total score	183	171	219	252
Acceptability (%)	**61**	**57**	**73**	**84**

Discussions

The system of maize-legume intercropping appears to address the constraints on short-term productivity in the maize-dominated smallholder farming systems we have studied. The benefits of introducing legumes either in crop rotations or through intercropping to increase yields in cereal-dominated cropping system is well-documented throughout Africa (e.g. Chikowo et al., 2006; Adjei-Nsiah et al., 2007; Ncube et al., 2007; Sileshi et al., 2008). Adoption of new technologies is often disappointingly low by resource-constrained farmers. It is therefore encouraging that the farming system that we studied addresses some of the drawbacks of many legume-based soil fertility replacement technologies. Resource-constrained farmers generally avoid additional risks and are reluctant to adopt new technologies that only have uncertain, future benefits (such as improved soil fertility) while incurring short-term costs such as increased labour demand, additional input costs or having to sacrifice areas of land to crops that do not directly contribute to either food security or farm income (Ajayi, 2007). The maize-pigeonpea intercropping system we have studied has the advantage of providing direct and prompt benefits in the form of significant additional income and food security through production of the legume grains. Besides being ecologically sound and more productive, the maize-legume intercrops clearly showed that they are economically viable with marginal rate of returns of at least 85%. Our study clearly shows farmers' production objectives are food security and income generation.

Studies reviewed by Snapp et al. (2003) suggest that maize and pigeonpea intercropped or grown in rotation can increase maize yields by 0.3 to 1.6 t/ha, even though it may take 2-3 years for beneficial effects of pigeonpea intercropping on maize yields to become evident (Chamango, 2001). Pigeonpea can be intercropped successfully with maize while maintaining the same density of maize as in a pure stand (Sakala, 1994). In such systems maize yields are not negatively affected by pigeonpea intercropping while an additional yield from pigeonpea is obtained as we have shown (Sakala, 1994; Myaka et al., 2006; Waddington et al., 2007). It is more common for weeding requirements to be lower in maize-legume intercropping systems due to the overall higher crop biomass and soil coverage (Chamango, 2001). Yield reduction of both maize and the pigeonpea have, however, also been observed when these crops were intercropped, with short-duration cultivars causing a larger yield reduction than long-duration cultivars (Mathews et al., 2001). The lack of clear response to P fertilization by pigeonpea that we observed might be due to its tolerance to poor fertility including low P content and low soil moisture conditions. In a review of the literature Odeny (2007) found that pigeonpea grown as a sole crop has the ability to fix up to 235 kg N/ha and produces more N per unit area from plant biomass than many other legumes. The deep root system means that pigeonpea has a better ability to anchor the soil, withstand severe drought than shallow-rooted legumes such as groundnut, cowpea and soybean. This ability to grow under adverse conditions combined with high N fixing potential means that pigeonpea has the potential to provide a substantial and reliable input of N to cereal-based cropping systems in drought-prone areas with soils of low fertility similar to our study sites.

Discussions with farmers revealed that they were enthusiastic about the direct benefits of pigeonpea as a source of income, as a staple food and as a source of high-protein feed for animals such as chickens. Our data suggests that there are indeed strong economic reasons why farmers may have chosen to include pigeonpea in their farming systems. Economic analysis of the experimental data provided indicates that pigeonpea is an important source of income, especially in cases when the maize performs poorly with marginal rate of return of at least 180%. This data was supported by farmers who mentioned that when maize performed poorly in the maize-pigeonpea intercrop, the pigeonpea would provide a much higher income than the maize grown on its own. Even with the successes we have mentioned here, not all farmers are practising maize-pigeonpea intercropping. We have observed that a greater proportion of the farmers are from the middle income group and a few from the richest group and none from the least resource group agreeing with other studies that poor farmers are risk averse (Okali et al., 1994; Conroy and Sutherland, 2004). It would make economic sense to grow pigeonpea on a large scale and use the proceeds to buy maize but farmers are not interested in such practices. Farmers mentioned the need to keep livestock out of the fields and not being able to let the livestock graze the crop residues as an important reason for not doing so. Lack of grazing is especially a problem towards the end of the dry season (September to November). However, successful farmers mentioned that targeting of pigeonpea to homefields reduced considerably the risk of livestock grazing in their fields before pigeonpea harvest in late August. Other reasons that were mentioned by farmers who had not adopted were lack of knowledge and scepticism as to the likely benefits of maize-pigeonpea intercropping.

Although there was an increase in weeding time in intercrops, this was not related to weed intensity but the need to take care of slow-growing pigeonpea plants as well as difficulty in navigating through the mixtures. Given that in the study sites labour is normally costed on the basis of area worked than the amount of time spend weeding, it is likely that the variation in weeding costs is very low between the treatments tested. Although very promising, the apparent success of the maize-pigeonpea intercropping system with some of the farmers in these villages does not imply that this technology can be assumed to be equally successful under other ecological (climatic and geological) and socio-economic settings (access to knowledge, traditions, access to input and output markets, etc.). The experiences of extension for promoting this practice and working for more than 10 years in these villages with maize-pigeonpea intercropping means that there is a wealth of experience that could benefit others wishing to replicate their successes elsewhere. Before embarking on any attempts to replicate the maize-pigeonpea intercropping technology there is a need to assess in more detail the costs and benefits of the system and to identify the socio-economic and ecological conditions under which this technology is most successful (Ojiem et al., 2006). In the site studied, farmers rely on a well established market of pigeonpea where all harvests are immediately absorbed yet challenges still remain as they are not entirely aware about the functioning of the market itself. They still need to be organised so that they can increase their bargaining power thus can negotiate for better prices. So despite the potential of pigeonpea in improving long-term maize yields and overall food (maize and legume grain) production and farm income, these benefits cannot be taken for granted. There is therefore a need to critically evaluate both the short and long-term performance of such systems when introduced in a specific locale. Neglecting this and assuming that the potential benefits of pigeonpea will be obtained under all conditions risks a mismatch between farmers' objectives and technology outputs. Our results also show that rainfall as well as its distribution is a very important determinant of crop yield but its extreme effects are easily offset in well designed intercropping systems.

Based on this research we can identify the factors that have contributed to the "fitting" of maize-pigeonpea intercropping within the farmers' circumstances. The success of the maize-pigeonpea intercropping systems is underpinned by strong extension support, strong market linkages and group selling of produce. On the biophysical side, the low soil fertility status of soils coupled with common mid-season dry spells favours pigeonpea because it is tolerant to these conditions, probably no other legume might achieve the same yield under these conditions. Maturity dates for maize and pigeonpea are three months apart thus labour demands are spread over time without putting a burden on its supply. There are opportunities in these systems to increase the practices of intercropping coupled with no-tillage, for example, farmers do not see the need for tillage when a ratoon crop of pigeonpea is used. Farmers have been involved in the system of maize-pigeonpea intercropping for a long time thus there are opportunities to improve at the practice level and not the experimental stage. Although farmers have been linked to markets for their produce, farmers are not always up to date about changes in prices and other conditions. Farmers reduce the costs of production by using retained seed for periods often over those normally recommended and this affects the quality of grain and thus reduces the prices of their produce.

Conclusions

Maize-legume intercrops are more productive, ecologically sound and with better linkages to improved markets, they are economically viable. Improved market linkages is a key driver in helping farmers move from predominantly cereal-based cropping to include legumes as discussions with farmers clearly showed that the drivers of intercropping were income generation and food security. Improved adoption of maize-legume intercropping especially with perennial legumes such as pigeonpea will lead to reduced need for tillage as a ratoon crop will be used in successive years. Challenges include the late maturity of pigeonpea which coincides with free roaming livestock but farmers have responded by targeting pigeonpea to fields close to their homesteads. However, farmers still need access to good quality and early maturity cultivars to completely overcome this challenge. On average, intercropping increased weeding time by 36% compared to sole crops for all the weeding times. However in the site, cost of weeding is based on the area worked on not the amount of time spend. Evaluations of the intercrop options by farmers show opportunities to improve the system and their continued involvement in research is important to tailor these technologies to their objectives and settings. We therefore conclude that maize-legume intercropping combined with reduced tillage reduces the risk of crop failure, improves productivity per unit area and ensures food security in vulnerable production systems. Maize-grain legume intercropping should be promoted as an alternative soil cover strategy in the sub-humid and semi-arid regions of southern Africa.

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