Feed the Future Mozambique
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Technical Brief: Building Resilience Through Intercropping

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Produced by:
Land O'Lakes Venture37
4001 Lexington Ave N
Arden Hills, MN 55126
www.landolakesventure37.org

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Cover page photo: Laurinda Chadreque, a farmer and wife of Lead Farmer Sanguirone, walks through their Model Family Farm in Barue, where maize and lablab bean are intercropped in the background. Photo credit: Ashley Peterson, Land O'Lakes Venture37.

Executive Summary

Climate change is a growing threat to smallholder farmers (SHFs) in sub-Saharan Africa and across the world — due to irregular rainfall, extreme weather events including hurricanes, shifting seasons, soil degradation, and increased pest infestations that can have devastating effects on farmers' livelihoods. SHFs face an urgent need to protect their livelihoods and protect our food supply. Farmers throughout Mozambique and the world have been intercropping a variety of crops in innumerable arrangements for centuries. Appropriately designed intercropping systems enhance the resilience of agriculture systems by increasing the productivity and profitability of fields for resource poor farmers. Since December 2016, the Feed the Future Resilient Agricultural Markets Activity – Beira Corridor (RAMA-BC), implemented by Land O'Lakes Venture37, has supported Mozambican producers to increase agricultural productivity, profitability, and resilience. RAMA-BC promotes the adoption of affordable and sustainable agricultural technologies and practices, including intercropping. RAMA-BC worked with the Universidade Eduardo Mondlane (UEM) in Maputo and Instituto de Investigação Agrária De Moçambique (IIAM) to conduct research on the impact of intercropping on maize yields and fall armyworm (FAW).

This technical brief summarizes the findings from this research in Mozambique, which found that intercropping can benefit communities by:

1) Increasing yield;
2) Reducing pests; and
3) Increasing returns on investment.

The brief further suggests that intercropping is an affordable and accessible solution for SHFs that does not rely on potentially harmful pesticides or other expensive inputs. Finally, the brief provides insights on how to further promote intercropping in similar contexts to ensure high adoption rates, namely by building on local existing capacities, expanding and strengthening diversity and connectivity of market relationships, and empowering local actors with options. Intercropping is a pathway to help resource poor SHFs improve soil health, reduce pest infestations, reduce labor demands, and increase productivity, thereby helping them adapt to and mitigate against climate change and increase their resilience — ultimately increasing their ability to cope with future climate shocks.

Legumes Promoted by RAMA-BC for Intercropping

RAMA-BC is promoting intercropping the legumes below with maize. All three legumes are edible and serve as nutritious sources of food.

- **Jack Bean** (*Canavalia ensiformis*): An annual or a biannual, herbaceous, very rustic, creeping legume with broad tropical distribution, widely used as a green cover to enrich the soil with nutrients (e.g., it fixes 120 to 280 kg of N per hectare). It is resistant to high temperatures and drought, is tolerant of partial shade, and is exceptionally resistant to insect attack. It has a productivity of 20 to 40 tons of green mass and 4 to 8 tons of dry mass per cycle.
- **Lablab Bean** (*Lablab purpureus*): A legume of Asian origin, creeping and with determinate (bush) and indeterminate (vining) varieties. It has fast early growth with little water and can quickly provide ground cover to protect soil from erosion. It is also popular for its nitrogen-fixing properties, contributing to improved soil quality, and is a great choice on infertile, acidic soils. It fruits a flat broad pod. When young, the pods and their nutritious seeds can be consumed.
- **Pigeon Pea** (*Cajanus cajan*): A semi-perennial, bushy legume with slow initial development. It mobilizes nutrients and recovers nutrients. First used as a windbreak and for livestock feed, the plant became very popular as a "soil builder" because it is excellent at fixing nitrogen, increases soil organic matter and improves soil structure and quality. It is a staple food crop that provides good protein. The green peas can be used like fresh peas, and the dried peas can be used to make popular pulses like dahl. Its leaves can also be eaten.

Introduction

Benefits of Intercropping

- Reduced need for fertilizer use, especially nitrogenous fertilizers
- Increased soil nutrients
- Increased soil moisture retention
- Reduced weeds
- Increased presence of pest predators
- Increased maize yields and total yields

Climate change is already — and will continue to be — a substantial contributor to the shocks and stresses that SHFs face daily throughout sub-Saharan Africa and the world. Intercropping can play an outsized role in reducing the impact of climate change and other economic stressors on SHFs through a multitude of benefits. Intercropping is the practice of growing more than one crop in a field at the same time (Horwith 1985). Maize is the primary staple food crop in much of Southern Africa. In the past, it has often been promoted with a viewpoint of a high input, high output model. Intercropping offers a solution that is much lower risk to the farmers but still with high returns, thereby increasing the likelihood that farmers will adopt it. Maize-legume intercropping benefits smallholder farming systems through increased land productivity, diluting crop production risk, and diversifying diets for farming families (Rusinamhodzi et al. 2017; Snapp et al. 2010). Legume intercropping improves overall system productivity, as measured in maize yield and total yield (maize yield plus legume yield), and it promotes yield stability. By contributing to a more stable yield over time and increased and diversified productivity, maize-legume intercropping increases SHFs' resilience capacities (Madembo et al. 2020; Mupangwa et al. 2020). As a climate adaptation strategy, intercropping has the potential to be widely adopted in similar contexts. Some reports even demonstrate that intercropping can, in some cases, mitigate greenhouse gas emissions and enhance carbon sequestration in soils (Drury et al. 2021).

Research has shown that soil health is greatly improved through intercropping. Leguminous plants improve soil fertility by increasing soil acidity, bringing phosphorous and magnesium to the surface, and fixing atmospheric nitrogen in their roots — thereby increasing access to essential nutrients for plant growth. Intercropping has also been shown to prevent soil erosion (Layek et al. 2018). Planting species in between rows utilizes space more efficiently. Intercropping can also be practiced sequentially in a season, typically achieving the same results ("The Green Manure/Cover Crop approach in RAMA-BC"). These elements generate substantial improvements in growth and yield for maize. In the diagram to the right, a legume is intercropped with maize. Intercrops attract natural predators of FAW, such as earwigs and ladybugs, and repel FAW ("Push and Pull to Control Fall Army Worm (FAW) and Striga"). In some intercropping systems, certain grasses such as Napier and Bana are planted around the perimeter of the field to attract FAW (Vandermeer 1989). Instead of actively planting grasses, a farmer can simply leave the natural vegetation around the field, serving as a similar "trap."

This reduction in pest damage also reduces the use of pesticides and the cost of inputs to the farmer, making it accessible for even extremely resource poor households.

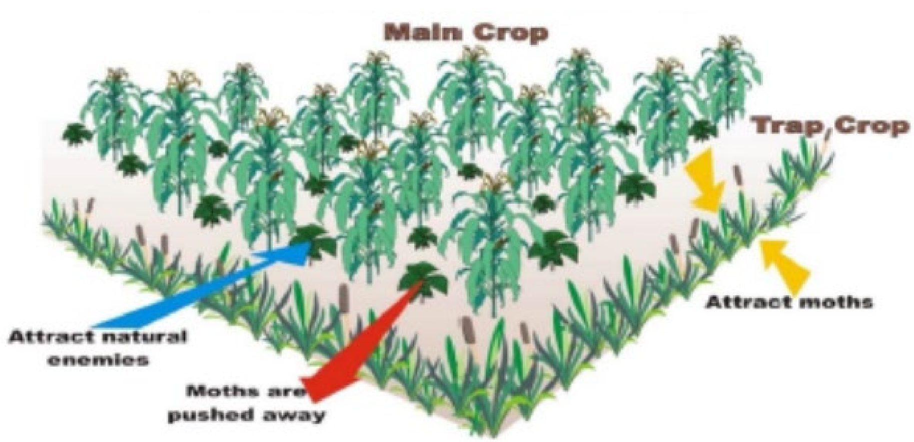


Figure 1: Schematic showing how intercropping a legume with maize pushes FAW away and vegetation around the field pulls FAW away from the maize. Source: Khan et al. 2010

Intercropping also reduces labor demands. By retaining more moisture in the soil, legumes can help suppress the spread of weeds. Reduced labor through intercropping benefits women, who generally perform most weeding activities. Increased crop yields through intercropping also leads to increased profits for SHFs.

While there are many approaches SHFs can take to improve their productivity and resilience, intercropping is an accessible, low cost, and highly effective practice that fosters resilience and requires only one additional input (locally available legume seeds). In this brief, we build on previous research by discussing specific benefits of intercropping: increased maize yield and total yield, increased presence of FAW predators which reduced FAW damage, and reduced labor demands, all of which ultimately result in increased return on investment (ROI).

Fall Armyworm (FAW)

FAW *(Spodoptera frugiperda)* is a moth native to the tropical and subtropical regions of the Americas and is now dispersed globally. Since it was first reported in Africa in January 2016, FAW has contributed to the damage of more than 80 different plant species, primarily cereal crops. Maize is the most severely affected cereal crop. FAW-damaged maize has led to significant food security issues and economic losses for tens of millions of SHFs and their families across the continent, including in Mozambique. By 2017, FAW was widespread throughout Mozambique, resulting in about 40 percent maize losses in 2018 primarily due to FAW (UN News 2018), compounding existing effects of climate change on maize production.

Mozambique Research Institution's Methods to Evaluate Intercropping

From 2018 to 2021, RAMA-BC worked with UEM and IIAM to conduct research on the impact of intercropping on maize yields and FAW. The six intercropping studies conducted by UEM in partnership with RAMA-BC evaluated the effect of intercropping maize with leguminous plants on (1) maize yield, (2) FAW predator occurrence, and (3) FAW infestation and damage severity. Two of these studies measured the effect of sowing dates on those three factors. Research took place across multiple districts in the Manica province including in Chiremera, Vanduzi, Macate, and Gondola. Using a Completely Randomized Block Design (CBCD), with four treatments and four repetitions, monocropped maize was compared to three intercropped treatment groups: (1) maize + jack bean, (2) maize + lablab bean, and (3) maize + pigeon pea.

Figure 2: Student measuring the presence of FAW in maize fields intercropped with lablab. Photo credit: RAMA-BC

In partnership with RAMA-BC, IIAM conducted a similar study to evaluate specific practices, including intercropping, on maize productivity. Trials were conducted in the districts of Barué, Sussundenga, Gondola, and Macate in Manica province and Nhamatanda in Sofala province. Monocropped maize was compared to the same three maize-legume intercropped treatment groups as the UEM studies. Additional data were collected in this study to measure labor demands and return on investment (ROI) from intercropping. Additional information on UEM and IIAM research methods can be found in Annex 1.

Research Results

These studies conducted by UEM and IIAM in partnership with RAMA-BC demonstrate that maize-legume intercropping increases maize yield and total yield, increases the presence of FAW predators thereby reducing FAW infestation and damage, and reduces labor demands. Taken together, these benefits contribute to an **increase of nearly 2.5 times in ROI for intercropped maize** compared to monocropped maize.

Intercropping Increases Maize Yield and Total Yield

Using cultural practices utilized by SHFs, intercropping legumes with maize increased maize yield from increased soil fertility and decreased yield losses from FAW compared to monocropped maize. IIAM research showed maize yield, when intercropped, was 13 to 32 percent higher compared to monocropped maize. Similarly, UEM research found intercropping resulted in 30 to 84 percent higher maize yields compared to monocropped maize. In addition to increasing yield, UEM data also demonstrated that intercropping reduced yield losses from FAW by 2 to 22 percent compared to monocropped maize alone. These results concur with the results of studies that also observed higher yields in maize intercropped with legumes (Tanyi et al. 2020).

In addition to increasing maize yield, intercropping legumes with maize **increased total yield** for that plot of land. The IIAM study found that total yield (maize yield + intercrop yield) was 66 to 101 percent higher in intercropped plots compared to monocropped plots (significant at the 5 percent level). This indicates that increased plant density does not result in decreased yields based on increased competition among plants; rather, total combined output of maize and legumes per hectare increased in the intercropped fields versus the monocropped plots. Importantly, as noted above, total output of maize per hectare in intercropped plots also increased versus the monocropped maize plots. In addition, some of the intercropped legumes, such as pigeon peas, are harvested up to five months later than maize. This staggered harvest is important for household food security. All together, these results have important implications for income generation, resilience, and nutrition outcomes.

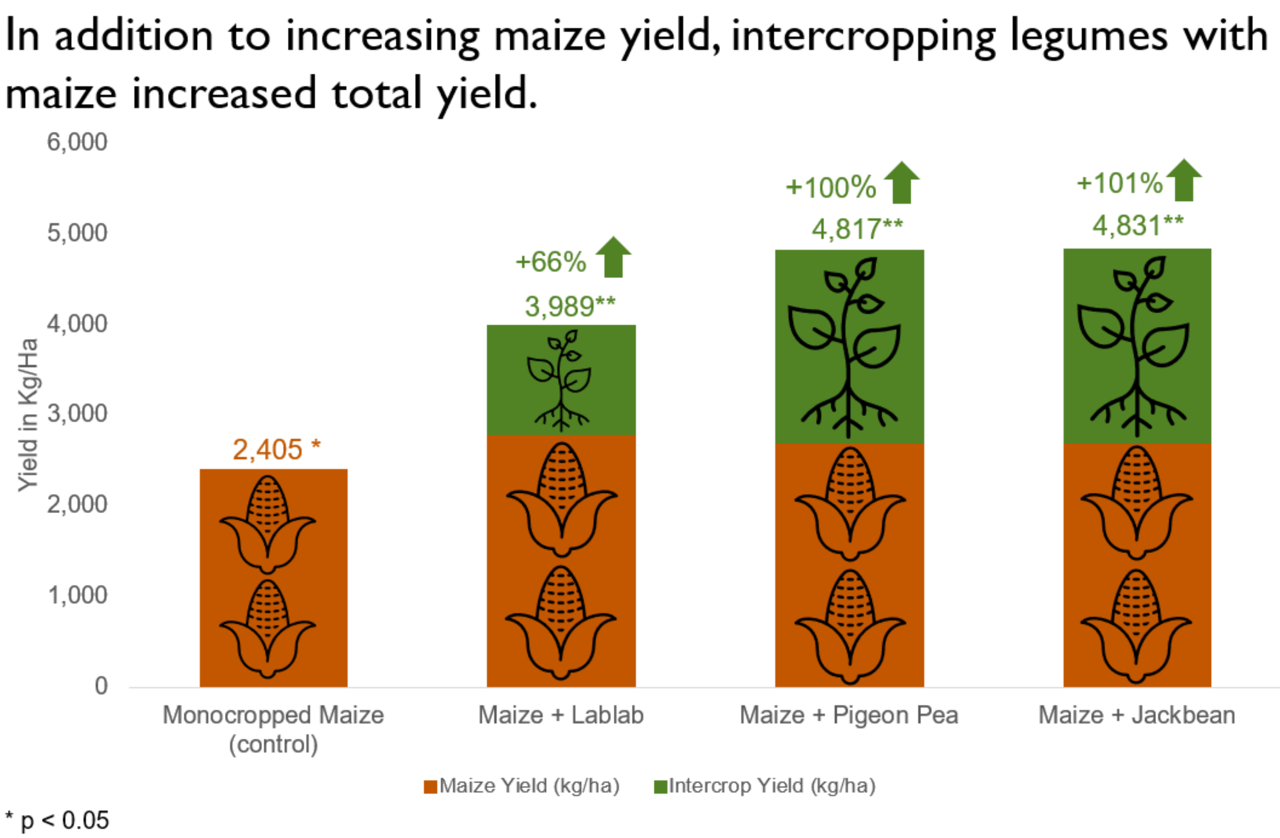


Figure 3: Maize yield and total yield were higher in intercropped plots than monocropped maize plots in the IIAM study. Total yield for all intercropped plots was significantly higher than monocropped maize; there was no statistical difference between the different legume intercrops. The percentage above each intercropped bar represents the percent increase in total yield from the control (monocropped maize).

Intercropping Reduces FAW Infestation and Damage through Predation

Intercropping maize with legumes resulted in a significantly higher abundance of predatory insects compared to maize alone (significant at the 5 percent level), increasing the natural biological control of maize pests including FAW. The most abundant predators found were earwigs (*Dorus luteipes*) and ladybugs (*Coccinellidea*) (both pictured in Figure 5). Predatory spotted lady beetle (*Coleomegilla maculate*), ants (*Formicidae*), and nematodes (*Hexamermis sp.*, which are FAW parasites) were also found. These predators serve as a form of natural integrated pest management for FAW, so farmers do not need to use pesticides or other means for controlling FAW or other maize pests, which are often expensive and may be harmful to themselves or the environment.

"When we kill a pest's natural enemies, we inherit their work."

- Dr. Carl B. Huffaker, University of California, Berkeley

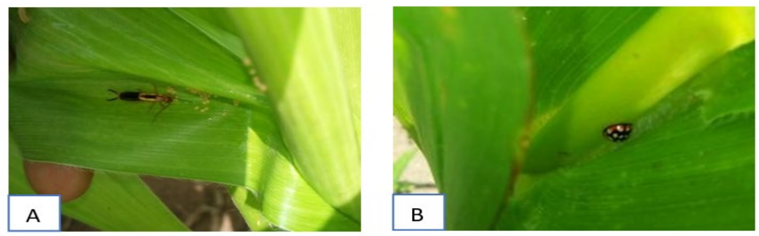


Figure 4: Earwig (A) and ladybug (B) on maize plants. Photo Credit: Babugi Ernesto, UEM.

In UEM research, the average abundance of FAW predators — earwigs and ladybugs — was significantly higher in intercropped maize fields compared to monocropped maize fields. There was no significant difference between the different legume intercrops**.** Peak FAW infestation levels and damage severity scores were also both significantly lower in intercropped fields compared to monocropped maize fields (significant at the 5 percent level). Maize intercropped with jack bean and pigeon pea had significantly lower damage severity scores compared to maize intercropped with lablab bean (significant at the 5 percent level). Peak infestation and damage occurred between 30 to 40 days after planting in all plots, and the cycle of infestation and damage followed the same course in monocropped and intercropped fields. These findings are consistent with research from Harrison et al. (2019), who reported that intercropping with legumes reduces pest damage by preventing moths from laying eggs probably by olfactory disruption, inhibiting larval movement between plants, and providing habitat for predators.

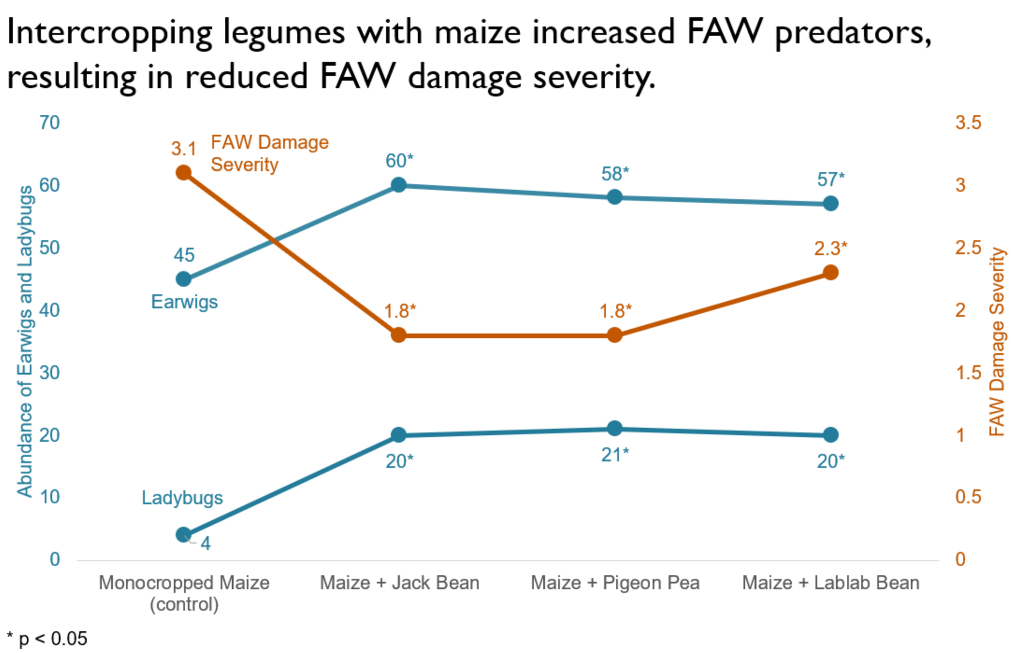


Figure 5: The average abundance of earwigs and ladybugs was significantly higher in intercropped maize fields compared to monocropped maize fields. This higher abundance of earwigs and ladybugs in the intercropped plots resulted in significantly lower FAW damage severity scores.

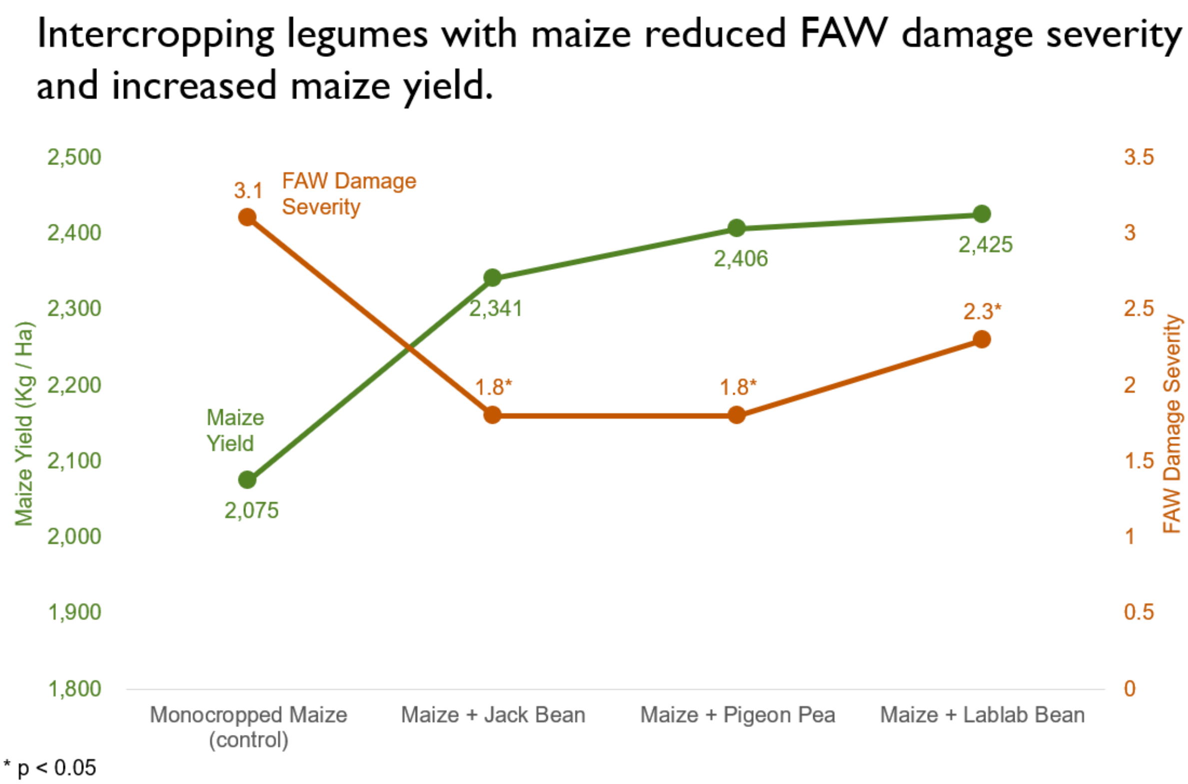
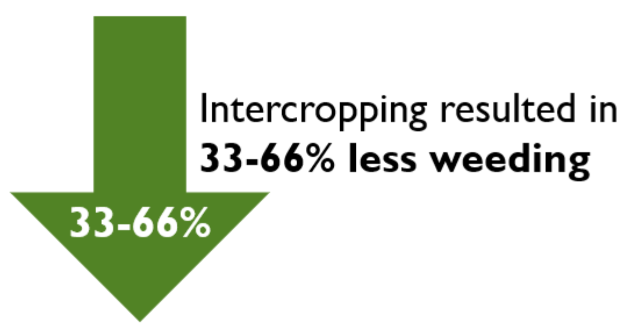


Figure 6: When comparing FAW damage severity from UEM research with maize yield from IIAM research, it is clear that intercropping legumes with maize leads to a reduction in FAW damage severity and increases maize yields. The maize yields in this figure do not exactly match the maize yields in Figure 3 because some plots were excluded from the total yield calculation due to flooding and livestock damage that occurred after maize had been harvested but prior to harvesting the legumes.

Intercropping Reduces Labor Demands

Intercrops act as living mulch or green manure by shading soil and suppressing weed growth. When intercrops reach a shading capacity above 50 percent, they positively influence soil moisture retention and weed control. Intercropping also diversifies production to break weed cycles (Lee and Thierfelder 2017). For example, the IIAM study found in Barue District that plots of maize intercropped with jack bean, pigeon pea and lablab saw 85, 71, and 66 weed plants present, respectively, compared to monocropped maize which had 242 weed plants.



As women are the ones who primarily weed in the household, reducing weeding time reduces drudgery and frees up time for women to perform other activities. The IIAM study showed that the need for weeding was reduced from three times per growing season with monocropped maize to one to two times with an intercrop present, which is a reduction of 33-66% in weeding intensity. These findings are consistent with research by Lee and Thierfelder (2017).

Intercropping Increases Return on Investment (ROI)

The IIAM study quantified the ROI for intercropping compared to monocropping, drawing from farmer-reported labor used for land clearing and preparation, sowing, weeding, and harvesting, as well as seed costs and yields. The study shows that through **increased yields and reduced labor**, intercropping legumes with maize resulted in an **average profit of $557 more per hectare**, which is nearly a three-fold increase in profits compared to monocropped maize. Intercropping also resulted in a nearly **2.5-fold increase in ROI** when averaged across both districts. The main difference in ROI between Macate and Barue is that farmers in Barue did not report weeding a third time on monocropped plots (nor on intercropped plots), so they spent the same amount of time weeding across all treatments. Farmers in Macate, however, reported weeding one less time for intercropped plots compared to monocropped plots. As noted earlier, IIAM research found many fewer weeds on intercropped plots compared to monocropped plots, suggesting weeding should be substantially lower for intercropping plots. Regardless of labor, farmers in Barue and Macate achieved substantially higher yields in intercropped plots compared to monocropped plots, resulting in a nearly two-fold increase in ROI for Barue and nearly a five-fold increase in Macate.

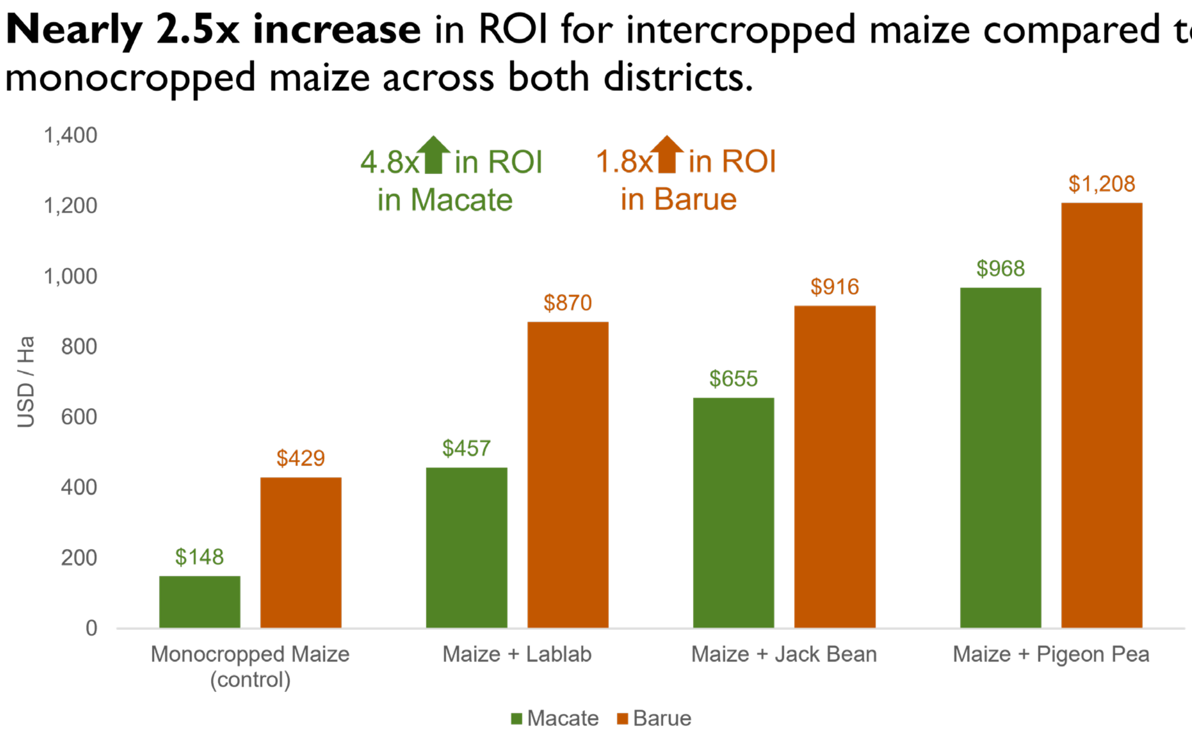


Figure 7: Increased yields and reduced labor demands on intercropped plots results in nearly a 2.5-fold increase in ROI compared to monocropped plots across both Macate and Barue.

Intercropping Adoption Requires Local Capacity Development and Strengthened Market Linkages

The results of the research shared here clearly demonstrate the many benefits of intercropping, namely increased maize yield and total yield, increased FAW predators and reduced FAW damage, reduced labor demands, and ultimately increased ROI. Farmers intercropping legumes with maize have increased resilience capacities through diversified and increased crop productivity that contribute to diversified and increased economic gains. However, despite these clear benefits, research over several decades has shown that there are **frequently many barriers** to adoption that prevent SHFs from adopting improved agricultural practices, including intercropping. RAMA-BC conducted a behavior change study in mid-2021 that examined the adoption of climate-smart agriculture practices, including intercropping, as well as barriers to adoption among program participants in two districts in which RAMA-BC works. Farmers reported a variety of barriers to adopting these practices that include socio-cultural, economic, ecological, and technical factors. **The most common barriers noted by farmers included**:

- Delayed start of the rainy season due to **climate change** causes labor constraints at planting time.
- Misunderstandings among farmers regarding weeds and soil structure reduce their interest in trying certain practices.
- Misunderstandings about how to implement the improved practices, including the labor needed for certain practices, prevent farmers from trying certain practices.
- **Lack of technical assistance** to help farmers adopt improved practices weakens their ability to correctly implement practices they are interested in trying.
- **Poor market access** and low and fluctuating prices of maize and other crops limits access to improved seed and restricts the desire of farmers to expand maize fields or diversify into cash crops like pigeon pea.

RAMA-BC incorporated three key approaches to overcome barriers like these and promote behavior change among SHFs and actors throughout the entire market system: **1) build on local existing capacities, 2) expand and strengthen diversity and connectivity of market relationships, and 3) empower local actors with options**.

Key Approaches to Promote Behavior Change

- **Build on local existing capacities:** Facilitate consistent, local technical support and guidance, such as supporting lead farmers, who have demonstration plots on their own land and supporting local universities to conduct locally applicable research and train future generations of researchers and practitioners.
- **Expand and strengthen diversity and connectivity of market relationships:** Expand market access for farmers and support the development of formal and informal market actors and the market system more broadly.
- **Empower local actors with options:** Provide options for SHFs and other actors — and equip them to make the best choice for themselves. Not all SHFs are the same, nor are all local agrobusinesses. They deserve options and the freedom to select what is best for them, their businesses, and their families.

First, RAMA-BC is building on the existing capacities of local actors, such as universities, who train future market actors, and local farmers, who serve as community-based extension agents. This technical brief is evidence of the strong collaboration RAMA-BC has had with local universities and research institutions, including UEM and IIAM. In addition to these collaborations, RAMA-BC has strengthened the curriculum of the University of Zambeze in Chimoio, contributing to strengthened capacities for future generations of researchers and practitioners. Additionally, RAMA-BC developed the model family farms (MFFs) approach to build local capacity among SHFs and their communities. MFFs tailor a bundle of technologies and practices that lead to healthier soils, efficient water use, diversified nutritious food production, and productivity gains. MFFs are established and managed by "lead farmers" who apply the improved practices on a portion of their own land side-by-side with their traditional practices, enabling them and their broader communities to directly compare the cumulative benefits of the climate-smart agriculture practices over time. Lead farmers were selected based on a number of factors, including their standing in the community, ease of access to and representativeness of their land, and their interest and ability to manage adaptive research and demonstration plots and share their knowledge with the broader community. MFFs serve as platforms for SHF capacity development and other social and nutrition behavior change activities. These varied activities have built on and further strengthened existing capacities throughout the market system.

Figure 8: Pigeon pea still covers the soil months after the rainy season ended. Photo credit: RAMA-BC

Second, RAMA-BC is expanding and strengthening the diversity and connectivity of market relationships, both in formal and informal markets. For example, RAMA-BC partnered with local seed companies in the formal market that developed locally appropriate seed kits that included drought-tolerant maize and complementary leguminous seeds for intercropping such as pigeon pea. The kits make it easy for SHFs to adopt intercropping and thereby strengthen their resilience capacities. Essentially, these input suppliers simplified intercropping by offering everything as packaged and right-sized bundles: the kits include seeds that are best for SHFs, packaged in suitable sizes at affordable prices for SHFs, and marketed appropriately to risk-averse SHFs. Additionally, RAMA-BC utilized MFFs and village savings and loan associations (VSLAs) as entry points to informal markets. Members of VSLAs accessed loans from the VSLA, allowing them to start up at least three agro-dealers, as well as other businesses such as agricultural input suppliers and commodity trading firms. RAMA-BC facilitated private sector-led farmer field days at the MFFs so these newly established agro-dealers could promote their products directly to SHFs. MFFs have also been used as launching pads for the multiplication of root crops such as improved varieties of cassava and orange-fleshed sweet potato, which feed into the informal market for dissemination. In addition to increasing SHF resilience, these partnerships have increased the diversity of actors in the formal and informal market system, improved products and services offered by those actors, and strengthened connections throughout the system.

Finally, RAMA-BC is empowering local actors with options. There is no silver bullet to improving SHF resilience, strengthening market systems or reducing poverty. Rather, actors need to be empowered so they can choose what is best for them — and they must be equipped to do so. In the UEM and IIAM studies, farmers' preference for each intercrop varied by location and across years. Farmers have a variety of reasons for selecting a given intercrop. RAMA-BC has empowered farmers by promoting several legumes as options for intercropping, allowing farmers to choose what is best suited for their farming system. Additionally, recognizing that access to finance, nutrition, and gender issues are all important factors related to building SHF resilience and reducing poverty, RAMA-BC promoted VSLAs among program participants, especially women, to facilitate access to finance to invest in climate-smart practices and technologies and/or other interests. RAMA-BC also trained VSLA animators on nutrition and gender issues, such as gender equality and gender-based violence. These animators then facilitated ancillary trainings for VSLA members on these topics, drawing on the videos and field manuals in the local language developed by RAMA-BC. Mass media (including locally based radio and TV) were also leveraged by the project to reach a broader audience. By incorporating all these related issues into RAMA-BC's agricultural work, RAMA-BC empowered program participants — especially women — with greater access to finance, knowledge, and support to help them achieve their own goals, whether they were related to adopting intercropping or other goals.

How to Implement Intercropping

RAMA-BC recommends the following steps for implementing intercropping in Mozambique and similar agroecosystems:

- Plant maize in rows 75 cm apart with 30 cm between plants, resulting in a density of 3 plants per square meter.
- Sow the intercrop legume simultaneously with maize. If a bi-annual legume such as pigeon pea is still in the field from the previous year, ratoon the legume at maize sowing.
- In areas where no maize is grown during the cool (dry) season, sow maize and the intercrop legume in November to December or when the first rains come, so the crops can escape the peak of FAW infestation.

RAMA-BC's approaches to strengthening local capacity and market linkages throughout the entire system have led to impressive results for the project. As of October 2021, approximately **21,000** individuals have adopted improved farming practices, including intercropping, on over **33,000** hectares of farmland. This sets a strong foundation for intercropping to be scaled across Mozambique. According to the Ministry of Agriculture, only 3.7 percent of SHFs in Manica and 1.9 percent in Sofala use fertilizer. Certified maize seed use is also low: 14 percent in Manica and 9 percent in Sofala (Republic of Mozambique: Ministry of Agriculture and Rural Development 2021). Intercropping serves as a proven alternative to other approaches that require substantial investment or inputs. Replication and scaling of intercropping across Mozambique would have profound impacts on SHF livelihoods, economic development and climate adaptation and mitigation. Strengthening formal and informal market actors and linkages at all levels is key to ensuring sustainable adoption of intercropping and building resilience for SHFs and the entire market system.

Call to Action

Farmers across the world are struggling as climate change presents an increasing list of challenges for agricultural communities. These problems range from crop-destroying weather events to the proliferation of invasive pest species, and they are especially devastating to under-resourced farmers, such as those in sub-Saharan Africa. This report, drawing on research from the RAMA-BC consortium, suggests that there is an accessible solution for SHFs to increasing crop yield, reducing pest damage, improving soil health, reducing labor needs, and increasing overall ROI in the face of climate change: intercropping. This practice is low risk, has few barriers to adoption, provides high returns, and can be used individually or in combination with other practices to improve farmers' resilience to climate change. RAMA-BC plans to expand the use of intercropping with annual crops, including incorporating tree crops and livestock through mobile pens to continue to strengthen SHF resilience ("Mobile Pens Harness Livestock to Improve Farm Systems"). All stakeholders have the responsibility to continue to share and support accessible agricultural solutions to build more resilient households and communities. These findings can help farmers, the private sector, public institutions, and non-governmental organizations alike effectively promote intercropping in practical and approachable terms. If intercropping was implemented by SHFs throughout Mozambique, those farmers would see increased incomes because of an expected 2.5-fold increase in ROI. If scaled around the world, such returns would result in dramatic improvements that would extend beyond the farm to positively impact entire communities.

Annex 1: Additional Information on Research Methods

In the UEM studies, trials were conducted under dry conditions with 20 plots measuring 10 meters by 10 meters over a period of four months. Rows were spaced 80 by 30 centimeters. Jack bean, lablab bean, and pigeon pea were sown between the rows of maize with a spacing of 50 centimeters between plants, resulting in 240 plants per plot. Two to three sowings were completed in the studies. Three sowing dates were used in studies measuring the effect of sowing time on FAW infestation. First sowing typically happened on or around December 29. Early sowing occurred on or around November 28 and late sowing on or around January 15. Harvest occurred on May 15. No fertilizers or pesticides were used in any of the trials.

To determine FAW infestation levels and occurrence of predators in the UEM studies, each plant was either visually examined or non-destructively assessed for the presence or absence of larvae on the leaves and in the funnel, and a percentage was calculated based on the formula from the Food and Agriculture Organization's Training of Trainers manual (2019). Due to the photophobic behavior of larvae of FAW, data collection occurred in the early hours of the morning. Sampling was done from 15 days after emergence (DAE) to 105 DAE at 15-day intervals.

In the FAW damage UEM studies, a systematic probabilistic sampling method was used. Data were collected at five points within each plot and ten plants observed at each point, totaling 50 plants observed per plot. Damage was rated on a 1 to 9 scale, the Davis and Williams scale, where the plants received grades from 1 to 9, with 1 to 3 referring to low damage, 4 to 6 medium damage, and 7 to 9 high damage (Davis et al. 1992).

Yield estimates in the UEM studies were based on IIAM methodology, where three sampling points were selected in each plot consisting of two consecutive parallel lines of 5 meters in length. At each point, all ears of the plants at the sampling point were harvested, shelled, and weighed using an overhead precision scale. After sun drying, the grain was threshed and weighed to measure yield.

In the IIAM study, the maize variety used was PGS 61, a long-cycle variety, sown soon after the first rains in November. The spacing used was 80 centimeters between rows and 25 centimeters between plants for maize, 25 centimeters between plants for lablab bean and jack bean, and 50 centimeters between plants for pigeon pea. All intercrops were sown 15 days after maize emergence.

The samples for soil analysis in the IIAM study were taken from each MFF field and were collected in a zigzag pattern, avoiding borders of the fields. The samples from each field were then mixed together, and a portion of the mixture was labelled and sent to the soil laboratory at Instituto Superior Politécnico de Moçambique in Chimoio for analysis.

The labor and ROI portion of the study also came from IIAM's research on MFFs. For labor calculations, the MFFs reported the number of hours they spent on each of the following tasks: land clearing and preparation, sowing, weeding, and harvesting. The ROI calculations drew from the following data: an average daily rate was used to calculate the average labor; average price of maize seed and intercrop seed, when applicable, were used and they were the only other inputs besides labor; and the total yield (maize + legume in intercropped plots) was used, with an average price per kilogram for each crop. An exchange rate of 63.2 Mozambican metical per USD was used. ROI for intercropping compared to monocropping was calculated by taking the difference in ROI for the monocropped maize plots and the intercropped maize plots.

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