3 Cereal–legume cropping systems for enhanced productivity, food security, and resilience

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Introduction

Millions of people in East and Southern Africa (ESA) remain at high risk of food insecurity. The main causes include poor crop productivity, soil nutrient deficiencies, erratic rainfall, and unsustainable farming practices. Maize is the major food crop and occupies large land areas. Many people's diets are heavily dependent on maize, which is produced inefficiently with little fertilizer, resulting in low yields. Maize is also lacking in essential nutrients, putting farming households at risk of nutrient deficiencies. Grain legumes are grown mainly for their high-protein seed, which provides a more nutritious diet than maize, and includes important macronutrients (proteins, fats, and dietary fiber), and essential micronutrients (vitamins and minerals). Grain legumes also obtain nitrogen from the air and accumulate it in the plant via a process known as biological nitrogen fixation, which takes place in the nodules on their roots (Figure 3.1).

Addressing the twin problems of malnutrition and poor soils requires diversification of maize-dominated cropping systems to include a substantial component of grain legumes. Farm production of protein-rich grains from legumes directly addresses the problem of poor access to food types that contribute to healthy diets. By fixing atmospheric nitrogen, grain legumes make it available to the host plant, thus providing nitrogen to companion and rotation crops. In the medium to long term, the high-quality legume residues and residues from cereal crops gradually build up soil organic matter, thereby supporting more sustainable crop production.

As a strategy to improve food and nutrition security, it is important to explore sustainable intensification options that increase grain yields within a short period, while also offering opportunities for crop diversification. Cereal–legume intercropping has been suggested as one such pathway (Martin-Guay *et al.*, 2018; Namatsheve *et al.*, 2020). Some grain legumes are also of interest as low-risk options for intensification of cropping systems, as they are adapted to drought stress (Franke *et al.*, 2017; Ojiem *et al.*, 2014). Enhanced productivity and nitrogen cycling is of particular interest to smallholder farmers, who generally struggle to afford (and obtain) external nutrient inputs (Tittonell and Giller, 2013). Cereal–legume intercropping could also constitute a natural biofortification method and may improve the nutritional composition of diets of farming households (Zuo and Zhang, 2009).

This chapter presents four approaches to the integration of legumes in maize-dominated systems, through intercropping, efficient spatial arrangements, and legume–cereal sequences:

- grain legume–maize rotations for increased yield stability on smallholder farms
- 'doubled-up' legume technology for soil fertility maintenance and human nutrition

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Figure 3.1. Nodules on the roots of a soybean plant. Specific soybean varieties require inoculation for these 'urea factories' to form successfully. (Photo courtesy of Jonathan Odhong, 2017.)

- innovative maize–common bean intercropping and fertilizer application for improved productivity
- targeted cropping sequences (rotations adapted to farm size limitations and farmer goals) and associated elements for sustainable intensification on small farms.

The first three technologies are based specifically on legumes that smallholder farmers can introduce to increase the productivity of their farms. The fourth demonstrates how different legume-based technologies can be integrated on farms with different resources, allowing farmers to diversify and intensify their production in a sustainable manner.

Grain legume–maize rotations

Background

Growing the same crop in the same place for many years in succession (monocropping) disproportionately depletes the soil of certain nutrients. This is why most farmers practice crop rotation. A cereal crop (e.g., maize) following a legume crop (e.g., groundnut) benefits from biological nitrogen fixation by the legume. Crop rotation also helps to reduce the build-up of pests and soil pathogens.

Grain legumes are generally bred to accumulate nitrogen in the grain component, giving a high nitrogen harvest index. The magnitude of the benefits of growing legumes to soil fertility depend largely on how the legume residues are used. When crop residues are taken off the field or burnt (as is often the case on smallholder farms as part of land preparation), the nitrogen input from the grain legume is nominal, or even negative. Thus, for both soil organic matter and nitrogen, it is necessary to retain the legume stover (plant leaves and stalks) in the field. This probably explains why cereal crops grown after a legume produce higher yields than would be explained from the addition of nitrogen alone. In general, grain legumes are less efficient than cereals at recovering soil inorganic nitrogen (Jensen and Hauggaard-Nielsen, 2003). This results in greater levels of inorganic nitrogen in the soil after a legume crop than after cereals, especially at deep layers. This is generally referred to as the 'nitrogen-sparing' or 'nitrogen-conserving' effect in legume–cereal rotation systems.

Description of the technology

Multi-location studies were implemented in central Malawi (over 20 field experiments conducted in the Dedza and Ntcheu districts), covering three agroecological zones, to validate the benefits of systematic rotations involving soybean, groundnut, groundnut/pigeonpea doubled-up technology, and continuous maize and pigeonpea intercropping over a four-year cycle. Two benchmark treatments were maintained: continuous maize with no fertilizer and continuous maize with fertilizer, using a general recommendation rate of 69 kg nitrogen/ha and 9 kg phosphorus/ha (Table 3.1). Each legume crop (Treatments 4–6 in Table 3.1) was rotated with a maize crop, with half the nitrogen and phosphorus application rate. All crop residues in these experiments were left in the field.

The experimental design aimed to demonstrate an ecological approach to help farmers reduce their dependence on industrial fertilizers, by maximizing biological nitrogen fixation in their fields. There were three main observed benefits. Firstly, crop rotations for all three legume systems (Treatments 4–6) resulted in similar maize yields for the plots with full-rate and half-rate fertilizer. Secondly, the soybean/maize and groundnut/pigeonpea doubled-up systems produced the largest yields of rotational maize, with quantities similar to the yields of maize with full-rate fertilizer (Figure 3.2). For smallholder farmers with poor access to industrial nitrogen fertilizers, the enhanced fertilizer use efficiency is a hugely positive benefit of the rotational systems.

Thirdly, for soybean, a small investment in purchasing inoculants with appropriate rhizobia strains (about US$ 5/ha) was required when growing specific varieties on a field that had not received rhizobia inoculations over the preceding two cropping seasons. This is because introduced rhizobia populations tend to decrease in soils over time, especially in acidic soils with poor soil organic matter. This small investment compares favorably with purchasing industrial nitrogen fertilizer, which costs around US$ 80 for 100 kg urea.

Benefits of the technology

The benefits of the maize–legume technologies in sustainable intensification of agriculture are summarized in Table 3.2. Yields of cereals grown after legumes are generally larger when compared with monocropping at similar fertilizer application rates. Also, farm families benefit from improved nutrition through the increased availability of dietary protein.

Farmers' responses

During the Africa RISING project, several farmers have expanded the area of their land planted to groundnut and soybean, mostly by about

Table 3.1. Cropping sequences involving continuous maize and grain legume–maize crop rotations

Treatment	Year 1	Year 2	Year 3	Year 4
1. Mz0	Maize, no fertilizer	Maize, no fertilizer	Maize, no fertilizer	Maize, no fertilizer
2. Mz69	Maize, full rate fertilizer	Maize, full rate fertilizer	Maize, full rate fertilizer	Maize, full-rate fertilizer
3. MzPp35	Maize + pigeonpea, full rate fertilizer	Maize + pigeonpea, half rate fertilizer	Maize + pigeonpea, half rate fertilizer	Maize + pigeonpea, half-rate fertilizer
4. SbRot	Soybean	Maize, half rate fertilizer	Soybean	Maize, half-rate fertilizer
5. GnRot	Groundnut	Maize, half rate fertilizer	Groundnut	Maize, half-rate fertilizer
6. GnDLR	Groundnut/ pigeonpea doubled-up	Maize, half rate fertilizer	Groundnut/ pigeonpea doubled-up	Maize, half-rate fertilizer

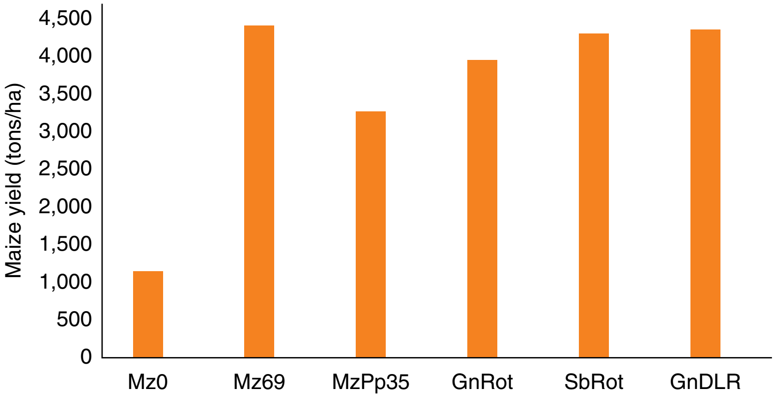

Figure 3.2. A comparison of maize grain yields in response to industrial fertilizer application only, or maize grown after grain legumes with reduced fertilizer application.

Table 3.2. Sustainable intensification with maize–legume rotations

Domain	Indicators	Magnitude of change
Productivity	Maize grain yield (t/ha) under nitrogen + phosphate fertilizer	+ 450%[1]
	Maize grain yield (t/ha) under rotations and reduced fertilizer use	+ 300%[1]
	Soybean yields with inoculation and phosphate fertilizer	+ 100%
Environmental	Biological nitrogen fixation	+ >40 kg nitrogen/ha
	Reduced soil erosion	
Economic	Increased fertilizer use efficiency for 50% fertilizer use after legumes	+ 60%[2]
Human nutrition	Increased protein production	+ 300 kg/ha annualized[3]

[1] Comparison with no fertilizer treatment.

[2] Based on agronomic nitrogen use efficiencies (kg grain/kg nitrogen applied).

[3] Based on soybean–maize rotation.

30%, with a few farmers expanding by more than 100%. This result was influenced partly by improvements in seed availability and opportunities for local consumption linked with Africa RISING training, especially for soybean. However, there has been limited uptake of sole cropping for cowpea and common beans, as these crops continue to be included as intercrops with maize. Farmers are adopting more sustainable crop rotations, with land increasingly being allocated away from cereals and toward legumes.

How to get started with soybean

(Other legumes are covered in separate chapters.)

Establishment

- Soybean needs moist soil for germination. They should be planted only once the rainy season has started properly (i.e., after a few days of rainfall).
- Make ridges that are 75 cm apart, just as for maize, so that the normal ridging system (for Malawi) is not disrupted by the production of soybean. Avoid ridges wider than 75 cm, as this results in sub-optimal plant populations or low yields.
- Plant two rows of soybean on each side of the normal ridge or within the furrows. Two rows per ridge/furrow (instead of only one) ensures a high plant population (>200,000 plants per hectare) and good yields.
- Within a row, drop (sprinkle) the soybean seeds at about 6—8 cm apart, depending on the agroecosystem. The seeds must be planted no more than 3 cm deep to ensure good germination.
- About 90 kg of seed is required to plant 1 ha. For varieties that are small seeded, use less weight of seed per hectare.
- Weed at least twice to keep fields weed-free, especially during the first month. With high plant populations, soybean will shade out other plants and control weeds (Figure 3.3).

Fertilizer

- When soybean is grown in rotation with a crop that received nitrogen, phosphorus, and potassium (NPK) fertilizer the previous season, the crop can be grown successfully without any direct fertilizer application.
- On poor soils, even if following a crop that received NPK fertilizer, apply a 50 kg bag of NPK (23:21:0) fertilizer per hectare at planting. This will help the nodules on the roots to function effectively.

Rhizobium inoculant

- Most of the soybean varieties available will need inoculant to stimulate growth of the nitrogen-fixing nodules on the roots.
- Mix the rhizobium inoculant with 200 ml of water plus a matchbox full of sugar for each 15 kg of seed. Sugar helps the inoculant stick to the seed. Pour the mixture over

Figure 3.3. A good soybean crop on a smallholder farm in Malawi. (Photo courtesy of Regis Chikowo, 2017.)

the seed and mix by hand in the shade (always do this away from direct sunlight to avoid killing the rhizobia).

- Read the instructions and inoculate the seed at the rate recommended on the packet instructions.

Harvesting and residue management

- Soybean should be harvested when the pods are mature and yellow-brown. Most of the soybean leaves that are clearly visible in Figure 3.3 would have fallen to the ground by harvest time, enriching soil fertility. A few seeds may be seen on the ground where the ripe pods have shattered. This is a clear sign to start harvesting.
- Cut the crop at the ground surface or uproot early in the morning when the plants are still damp with dew. Immediately transport the harvested soybean when still damp. If soybean is harvested and carried in the midday sun, many pods will shatter, and the seeds will be lost.
- After a few days of further drying, the plants can be threshed with a stick and winnowed (seed separated from the pods).
- The residues of leaves, stems, and pods makes a good mulch or can be composted for application to the fields the following season. To realize the full soil fertility benefits, the nitrogen-rich crop residues must not be burnt. Some of the residue can be used as animal feed so long as most is left on the field.

Doubled-up legume technology

Background

Between 2000 and 2018, sub-Saharan Africa achieved the highest rate of growth in agricultural production value of any region in the world, expanding by 4.3% per year, roughly double that of the prior three decades (Jayne and Sanchez, 2001). However, roughly 75% of its crop production growth came from expansion of the area under cultivation, and only 25% from improvements in crop yield. While there is still abundant land for agricultural expansion in some countries in Africa, many others have few opportunities due to rapid population growth. In Malawi, for example, land expansion for cultivation is no longer feasible, with farm sizes becoming smaller due to land fragmentation. Thus, area expansion must be replaced by increasing crop yields on existing farmland. Higher productivity can be achieved through intercropping, especially in low-input systems. The doubled-up legume technology is a special type of intercropping, in which two grain legumes with different growth habits are grown together, resulting in increased land productivity, better human nutrition, and benefits for the environment.

Description of the technology

The doubled-up legume intercropping technology consists of two legumes planted together at the same density as would normally be grown individually, so doubling the number of plants on each field. It involves intercropping pigeonpea with a grain legume, with both legumes grown at near their optimum populations (Smith *et al*., 2016). The success of the doubled-up legume technology depends on the initial slow growth of pigeonpea over the first three months, with rapid growth occurring when the companion understory grain legume has nearly reached maturity.

The most successful doubled-up cropping system involves a combination of groundnut and pigeonpea (Figure 3.4). After harvesting the groundnut component, pigeonpea continues to grow as a sole crop. Combinations of cowpea or soybean with pigeonpea are also possible. The different growth habits for this novel legume–legume intercrop results in minimal intra-specific competition for nutrients, water, and sunlight, while also adding nitrogen-rich leafy material to the soil. The system doubles biological nitrogen fixation while also ensuring a yield from both legumes. A sole maize crop grown in rotation with the doubled-up legume technology can be grown successfully with little fertilizer, due to the soil fertility benefits of the doubled-up system.

Benefits of the technology

Table 3.3 summarizes the benefits of the doubled-up legume technology on grain yield. The groundnut/pigeonpea combination invariably produces higher yields in a doubled-up system than with a sole crop. The soybean/pigeonpea system sometimes shows a yield decrease for the pigeonpea component. This may occur in conditions

Figure 3.4. Groundnut/pigeonpea doubled-up system providing double grain and soil fertility benefits. (Photo courtesy of Jonathan Odhong, 2015.)

of good soil fertility, where the soybean may grow too vigorously and shade out the slower-growing pigeonpea plants.

The nitrogen input benefits associated with the doubled-up system can be substantial (Table 3.4) and were confirmed in the validation study (Table 3.5). The wide ranges shown in Table 3.4 reflect differences in agroecosystems and management. The groundnut/pigeonpea system confers the best soil chemical quality gains through biological nitrogen fixation inputs. For small farms, therefore, the groundnut/pigeonpea system presents a substantial opportunity for sustainable intensification, with additional crops produced on the same area of land.

Further benefits of the technology include the potential for crop diversification on small land holdings. Farmers have welcomed this technology as it enables them to maintain their normal maize production as well as harvesting an extra crop on the same size farm. Intensified production using double rows results in less weed pressure, with the weeds being smothered by the dense crop canopy. This reduces the burden on women and children, who provide most of the labor required for weeding. The soil remains covered with plants well after the main harvesting season for crops such as maize, soybean, and groundnut. Prolonged soil cover reduces wind and water soil erosion, and is therefore good for the environment, and reduces global warming (Kaye and Quemada, 2017). Finally, farmers do not need to apply as much industrial fertilizer in the subsequent maize season. In the validation study, a 50% reduction in fertilizer use on the maize crop in rotation with the doubled-up technology resulted in financial savings on fertilizer of about US$ 80 per hectare.

Farmers' responses

The doubled-up legume technology is gaining popularity, especially in southern Malawi, where household land holdings are frequently less than 0.5 ha. Farmers need to grow maize for food security and disproportionately allocate most of their fields for maize production. In southern Malawi, pigeonpea has traditionally been intercropped with maize. This tradition is gradually being replaced with the groundnut/pigeonpea system, which makes production of a rotational maize crop more economical due to lower requirement for fertilizer. During a field day in Kandeu, one farmer stated: "groundnuts and pigeonpea are buddies in the field". This was very

Table 3.3. Assessing the productivity of the doubled-up legume technology

	Grain yield (kg/ha)			
Cropping system	Groundnut	Pigeonpea	Soybean	LER[1]
Sole crop	800–1,500	330–950	800–2,000	n/a[2]
Groundnut + pigeonpea	700–1,200	253–640	n/a	1.20–1.48
Soybean + pigeonpea	n/a	200–600	500–1,300	0.80–1.44

[1] The land equivalent ratio (LER) is used as a measure of the productivity of intercrop systems versus sole cropping. LER = [intercrop 1/pure crop 1] + [intercrop 2/pure crop 2]. LER > 1 indicates that intercropping is advantageous.
[2] n/a = not applicable.

Table 3.4. Nitrogen inputs through biological nitrogen fixation

Cropping system	Nitrogen fixed (kg/ha)	Source[1]
Sole groundnut	21–102	a
Sole soybean	36–74	b
Sole pigeonpea	45–120	a, b
Groundnut/pigeonpea	50–148	a, b
Soybean/pigeonpea	50–110	b, b

[1] Source: a = Mhango *et al*. (2017); b = Njira *et al*. (2013).

Table 3.5. Validating the benefits of the double row planting and doubled-up legume technology

	Productivity		Biological nitrogen fixation		Nutrition	
Technology	Yield (kg/ha)	% change	Nitrogen input (kg/ha)	% change	Crude protein (kg/ha)	% change
Sole groundnut (single row)	950	n/a[1]	44	n/a	247	n/a
Sole groundnut (double row)	1,400	47	74	68	364	47
Sole soybean (single row)	1,100	n/a	42	n/a	440	n/a
Sole soybean (double row)	1,600	45	66	57	640	45
Sole pigeonpea	635	n/a	85	n/a	132	n/a
Groundnut/pigeonpea	1,200 450	n/a	120	41[2]	418	15[2]
Soybean/pigeonpea	900 240	n/a	110	29[1]	695	10[3]

[1] n/a = not applicable.

[2] Gains over sole pigeonpea.

[3] Groundnut or soybean are the main crops in the intercrop.

encouraging to hear, as it reinforces empirical data that show little intra-specific competition between the crops.

How to get started

Establishment

- The doubled-up legume technology is best implemented by intercropping pigeonpea with groundnut or cowpea.
- Groundnut must be planted early to coincide with the first effective rains. A delay in planting will cause a marked drop in yield. Planting two rows of groundnuts per ridge increases groundnut density, resulting in optimal plant populations.
- On the ridges already planted with groundnuts, plant three or four pigeonpea seeds per planting station at 90 cm spacing. This results in about 44,000 plants per hectare. The single row of pigeonpea must be planted at the center (top) of the ridge. It takes 8 kg of pigeonpea seed to plant 1 ha of grain legume/pigeonpea doubled-up system.
- In this intercrop, the grain legumes are harvested first, leaving the pigeonpea as the only crop in the field for several weeks.

Fertilizer

- When a doubled-up intercrop of groundnut/pigeonpea is grown in rotation with a crop that received NPK fertilizer the previous season, there is no need to apply fertilizer that year.
- On poor soils, even if following a crop that received NPK the previous year, apply a 50 kg bag of NPK (23:21:0) fertilizer per hectare at planting. This will supply the nitrogen required by the legumes before biological nitrogen fixation sets in, as well as phosphorus that is essential for the functioning of the root nodules.
- There is no need to apply urea fertilizer to doubled-up legumes. Once established, these crops manufacture their own nitrogen.

Harvesting and residue management

- Harvest groundnuts when the pods are mature. After plucking the pods, retain the crop residues in the field or use the residues to make high-quality compost.
- Depending on the pigeonpea growth duration, harvest the pigeonpea pods when they are brown and produce a rattling sound when shaken (around 6–10 weeks after harvesting the groundnut).

- The benefit of the pigeonpea to next year's crop on that field (usually maize) is due to the large amount of pigeonpea leaves that fall to the ground as the crop matures, providing a high-quality residue to enrich soil fertility.
- Never burn the pigeonpea crop residue. Some may be fed to animals, but most should go back into the ground.

Maize–common bean intercropping and fertilizer application

Background

Common bean (*Phaseolus vulgaris)* is a bush bean normally grown by farmers as an intercrop with maize. Farmers tend to grow a single bean plant between each maize plant, but this practice limits the productivity of the beans, especially when compared with a bean sole crop. Africa RISING research reveals that increasing the bean plant population in a maize–bean intercrop – by planting beans between **and** next to the maize plants – can benefit the productivity of both maize and beans, as well as improving soil fertility. Since the two crops mature at different times, there is little competition for soil resources. In fact, the beans benefit from water flow down the maize stems, which results in soil wetting, even in conditions of low rainfall. The beans also benefit from the application of industrial fertilizer applied to the maize during basal dressing, with increased fertilizer recovery by the two crops.

Africa RISING tested maize–common bean intercropping, with beans intercropped by planting between the maize plants (BMS) and next to the maize plants (NMS). The validation trials took place in central Malawi (Dedza and Ntcheu districts), where common bean provides 74–90% of dietary protein and 25% of household income for farming families. The Dedza site is at an altitude of 1,400 m above sea level (masl), and is classified as high-potential agroecosystem, receiving about 1,000 mm of rain annually. The Ntcheu site is at an altitude of 850 masl, with a relatively cool climate. The intercrop technology has good potential to be scaled up and out elsewhere in ESA in areas of similar agroecosystem and where land holdings are small.

Description of the technology

The success of combining BMS and NMS is based on the fact that bush beans have a shorter duration to maturity compared with maize. Competition for light and other environmental resources is therefore minimal during the early and critical stages of crop development, even when both crops are planted at the same time (Figure 3.5). The bean plants will supply some of their required nitrogen through biological nitrogen fixation, sparing the nitrogen applied as fertilizer to support the growth of the maize. Generally, crops do not use more than 20% of the applied phosphate fertilizer (Syers *et al.* 2008), therefore, the bean intercrop will not negatively affect phosphate supply to the maize plants.

Benefits of the technology

This technology produces larger plant populations than traditional farmer practices. Eight on-farm trials conducted in central Malawi during two rainy seasons (2013/14 and 2015/16) showed that, without fertilizer, yields of the two intercropped bush bean varieties SER45 and SER83 increased by 85% and 96% compared with farmer BMS practice. Under fertilizer application, SER45 and SER83 showed improved yields (1,830 and 1,236 kg/ha, see Table 3.6). Net income was calculated to assess the profitability of each technology by using actual input costs and the value of the harvested crop. Labor costs were not included due to lack of data on total labor requirements for each system, and the complexity of appropriately valuing the opportunity cost of household labor, in line with other similar studies (e.g., Snapp *et al.*, 2018). Associated input/output prices were based on a combination of prices received by farmers and from the project monitoring in the study sites. Despite the additional cost of buying improved seed, the sustainable intensification options produced larger net incomes for the combined BMS and NMS technology.

The technology is suitable for scaling up to benefit food security and incomes among

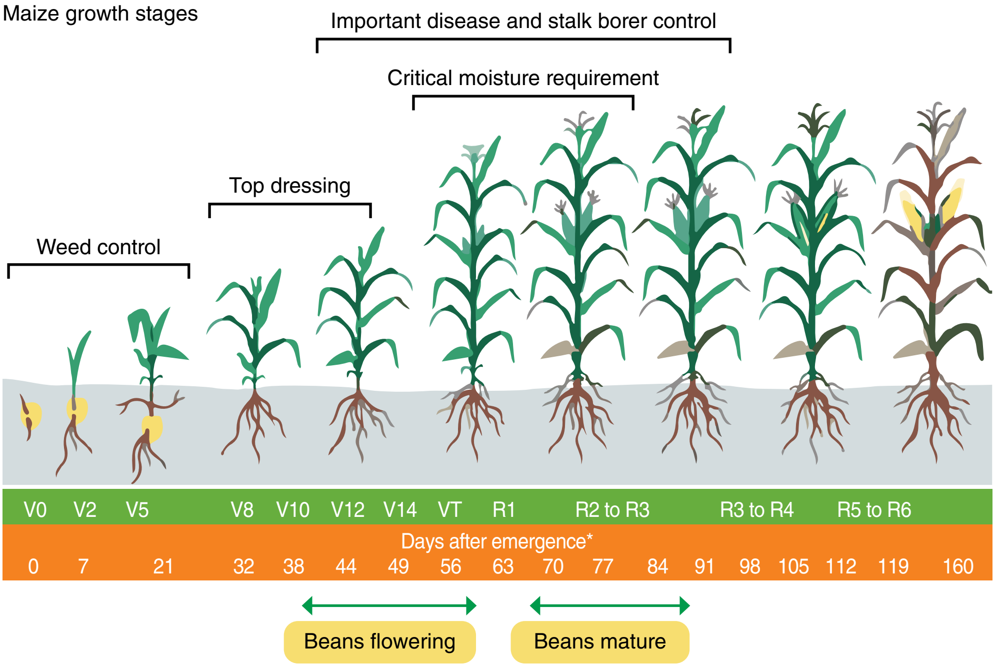

Figure 3.5. Maize development in days after emergence, compared with flowering and maturity stages for common bean. V0 to V14 are maize vegetative growth stages, VT is the tasseling stage, and R1 to R6 are reproductive stages (* the number of days varies between growth classes and environment). Adapted from Pringle (2017), reproduced with permission from Pannar Seed.

Table 3.6. Benefits of maize–bean intercropping, based on bean grain yield

Bean variety	Technology	Yield (kg/ha)	Change (%)	Net income (US$/ha)	Change (%)
SER45	Farmer practice	632	n/a[1]	501	n/a
	BMS + NMS	1,172	85	1,099	119
	BMS + NMS + fertilizer	1,830	189	1,827	264
SER83	Farmer practice	561	n/a	415	n/a
	BMS + NMS	1,103	96	1,009	141
	BMS + NMS + fertilizer	1,236	120	1,154	178
	LSD[2]	152			
	P	<0.01			

[1] n/a = not applicable.

[2] LSD = Least significant difference.

small-scale farmers throughout ESA. Most smallholders have land holdings, often less than 0.5 ha, of which they usually set aside very small areas for bean production (Kamanga, 2011; Snapp *et al*., 2002). Using this intercropping technology allows them to grow beans in a much larger area and secure a correspondingly larger harvest. Farmers currently do not apply industrial fertilizer to beans when grown as a sole crop (Kamanga *et al*., 2010). The intercrop system will boost bean productivity, since the beans can benefit from the fertilizer, especially phosphate, applied to the maize. Another benefit relates to improved soil fertility resulting from growing beans on a larger area.

Farmers' responses

Farmers in Malawi have been using non-drought-tolerant local bean varieties in the maize-bean intercrop where bean is planted between the maize stations. In the past, these local varieties thrived, because a normal crop season would have rains starting in October and running through to early May. However, over the past ten years, the rainfall seasons have been shorter, running from December through to March or April, resulting in terminal droughts and poor harvests. Integrating improved drought-tolerant and early-maturing bush bean varieties (SER83 and SER45) in the maize—bean cropping system, where the bean is planted next to the maize plant as well as between the maize plants is gaining popularity because farmers are able to harvest more beans than previously. Fifty-three farmers (29 male and 24 female) were involved in Africa RISING trials in Linthipe, Dedza district, and nicknamed the drought-tolerant varieties *nthetsa njala*, meaning "no more hunger". The increased productivity contributed to improved household food and nutrition security, as well as incomes. The farmers were pleased with the new technology since it provides increased yields on the same land area, and because they could still harvest beans, even in shorter rainy seasons.

How to get started

- Choose a field that is not waterlogged, as beans do not grow well in such soils.
- Prepare land and make ridges/rows at a spacing of 0.75 m. This ridge/row spacing provides the optimum plant population for maize, which is the main crop in the intercrop. Plant spacing can be adapted to different countries and agroecosystems based on the growth characteristics of the available maize varieties.
- Soon after the first rains, plant one maize seed per station at an intra-row distance of 25 cm, and beans on the same planting station with maize, as well as at 12.5 cm from the maize plants (Figure 3.6).
- Apply basal fertilizer at a rate of 23 kg nitrogen/ha and 21 kg phosphate/ha in a hole 5–7 cm deep between two maize plants, 5 cm from the central bean plant (Figure 3.7). This can be adapted to any NPK compound fertilizer, based on soil fertility status.
- Top-dress with urea at 46 kg nitrogen/ha, applied 21 days after planting. The application method is the same as that for basal dressing.
- Weed as soon as the weeds appear, but weeding should not be done during the bean flowering stage, as this will shake off

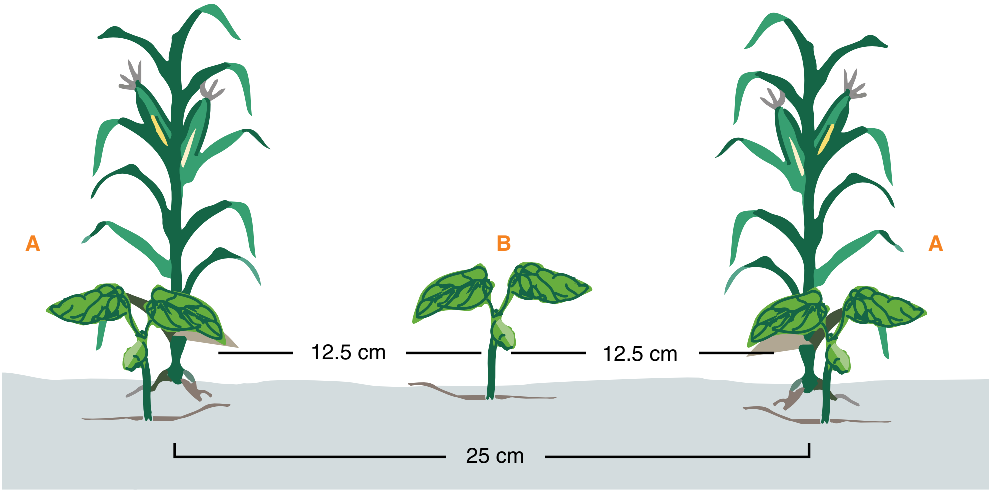

Figure 3.6. Intercropping pattern for the maize–bean intercrop. A = NMS and B = BMS.

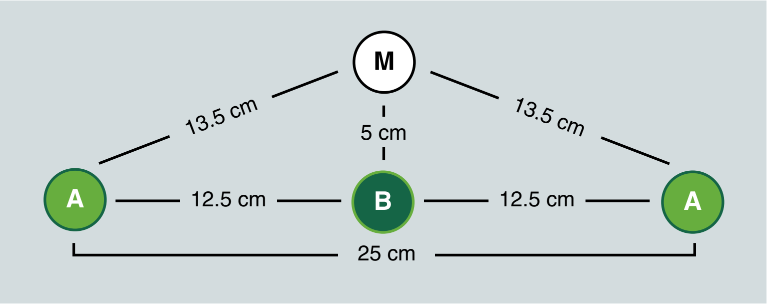

Figure 3.7. Fertilizer application in maize–bean intercrop on a ridge. A = NMS and B = BMS. The white oval represents the point where fertilizer is placed for both basal and top dressing.

the flowers and could negatively affect the podding process.

Targeting cropping sequences

Background

Maize is the main cereal crop in Malawi, but much is produced inefficiently, grown on poor soils containing little organic matter. Investment by farmers in expensive fertilizer will only produce attractive results in conditions of high fertilizer use efficiency, which relies on sufficient soil organic matter. However, on most small-scale farms, soil organic matter has been degraded over many years of cultivation. Integrating legumes at a large scale is one approach to increase soil organic matter and nitrogen cycling in soils, thereby increasing the productivity of the maize grown in sequence. The practicalities of integrating legumes with cereals depends on a number of factors, chiefly the amount of land the farmer can cultivate. Currently, many very small farms are wholly cropped with maize, reflecting farmers' desperation to meet their family's calorie requirements, but this is an unsustainable option.

Technological interventions to address the problem of poor productivity of smallholder agricultural systems must be designed to target spatially heterogeneous farms, and to address limited land access as a constraint to farmer innovation. Implementation of linear and top-down approaches that do not sufficiently recognize such complexity can too often result in failed research and development efforts. It is therefore important to match different technologies to individual farmers' land holdings and other resources. Access to quality land drives the intensity of fertilizer use and has a critical role in organic matter flows among farms of different resource endowment and production orientation, leading to large variation in soil fertility status and crop productivity.

Description of the technology

This cropping system-based technology consists of guidelines to help farmers identify the best opportunity for increasing productivity on their farm over the short and long term. It addresses the fact that farmers have different constraints limiting their ability to implement proven technologies and suggests crop diversification as a means of providing improved food security and nutrition.

Africa RISING researchers identified two main types of farms: low-resource farms (<0.6 ha) and resource-endowed farms (>1.2 ha). This was based on an earlier extensive literature review (Chikowo *et al.*, 2014) and four years of participatory action research in central Malawi with hundreds of farmers. The researchers then designed legume-based sustainable intensification interventions for the two distinct farm types.

Resource-constrained small farms (<0.6 ha) have few livestock, low incomes, and poor food security. For these farms, low-input combinations of maize–legume intercrops and pigeonpea intercropped with groundnut (doubled-up technology), with targeted use of fertilizer provided a viable way to improve stagnated yields (Figure 3.8). These farmers often lack access to industrial fertilizers and improved germplasm with high yield potential. Sustainable production can be achieved with a combination of maize–bean or maize–pigeonpea intercropping for 65–70% of the farm, and groundnut/pigeonpea doubled-up legume technology for the remainder.

During Year 1, about two thirds of the 0.6 ha farm could be cropped with a maize–bean or maize–pigeonpea intercrop, depending on the agroecosystem. The groundnut/pigeonpea doubled-up legume technology would occupy the rest of the farm. During Years 2 and 3, the crop mixtures are maintained, but the one third of the farm planted with the doubled-up legume system must be changed every year to a different part of the farm. This is because the large input of nitrogen added via leaf fall will build up soil fertility for the entire farm over a three-year cycle. This cropping design is unique in that the entire area of cropped land has a legume component each cropping season, adding to crop diversity.

The farmers with resource-endowed farms (>1.2 ha) demonstrated a preferential interest in growing soybean or groundnut as sole crops. These farms were recommended to grow maize (with fertilizer) on 50% of the farm, in rotation with grain legume crops (Figure 3.9).

During Year 1, half of the 1.2 ha farm would be sole cropped with an improved maize variety that receives modest amounts of fertilizer (12 kg phosphate/ha and 69 kg nitrogen/ha), with the remaining half planted with grain legumes. For example, the non-maize fields could be planted with groundnut, cowpea, and inoculated soybean, all receiving about 12 kg phosphate/ha. After harvest, crop residues are left in the field and incorporated at land preparation, with some fed to livestock.

During Year 2, maize is grown in the area previously cropped with legumes, while the legumes are planted in the fields that had maize the previous year. In Year 3, the cropping pattern would revert back to the Year 1 scenario, but with an option to reduce nitrogen fertilizer application on the maize crop. The legumes can be grown solely with residual fertility, with no additional fertilizers. This cropping schedule meets multiple goals: it follows meaningful crop rotations, allows farmers to participate in grain legume markets, and helps them achieve self-sufficiency in maize.

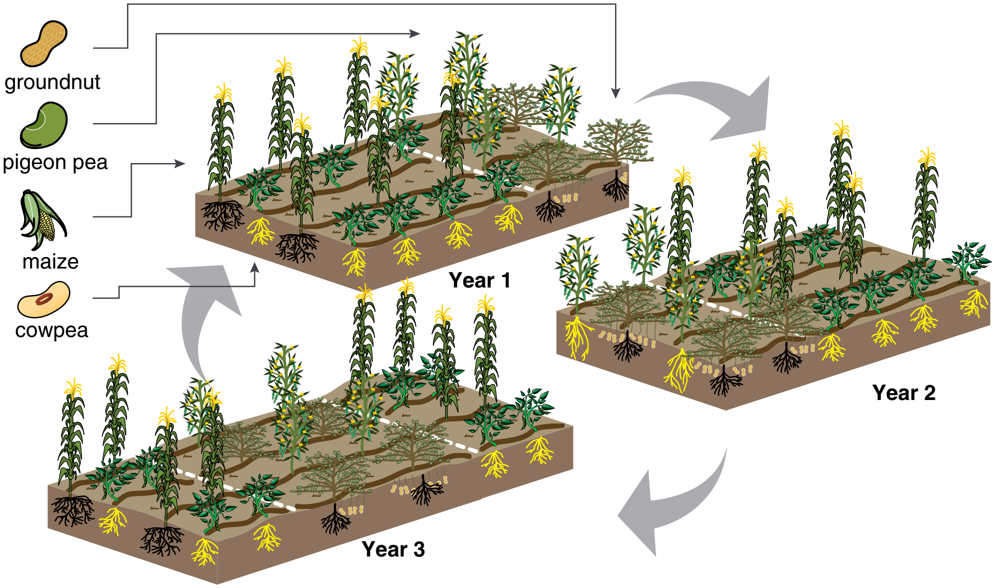

Figure 3.8. Application of maize–cowpea intercropping and groundnut/pigeonpea doubled-up legume technology on resource-constrained farms (<0.6 ha).

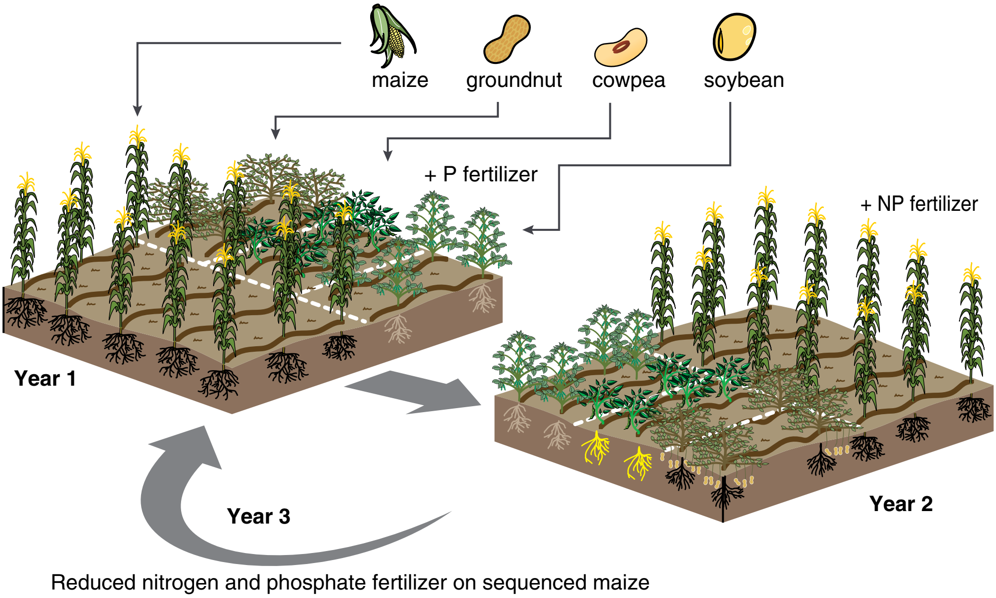

Figure 3.9. Maize and grain legumes (soybean, groundnut, and cowpea) with fertilizer in rotation on resource-endowed farms of >1.2 ha. Legumes occupy 50% of the land area.

Benefits of the technologies

Poorly resourced, small farms with degraded soils may require a lag phase, in which soils must be rehabilitated, mainly through the pigeonpea/groundnut doubled-up legume technology. For poor farmers who can afford only limited inputs, soil fertility is likely to deteriorate further with grain legume–maize rotations alone. The doubled-up system provides a much-needed stimulus through the larger crop residue inputs provided by the pigeonpea, and the associated larger nitrogen cycling. Also, the prolonged soil cover through the semi-perennial pigeonpea shrubs results in reduced erosion, protecting the topsoil from losing organic matter that is essential for the soil restorative process.

Farms with non-degraded soils and with access to external inputs are able to immediately implement industrial fertilizer or manure-based technologies to intensify maize production, as well as grain legume–maize sequences. Because they can access fertilizers and organic resources, they have generally maintained high levels of soil organic matter, one of the key requirements for high nutrient use efficiency.

Farmers' responses

Farmers across all sites are aware that their soils have been degrading over the years, and there is a need for sustainable intensification technologies and practices to restore soil fertility and boost productivity. As highlighted elsewhere in this handbook, food self-sufficiency through maize is the primary goal of the majority of farmers. Unfortunately, at current productivity levels, transitioning to the 50:50 cereal:legume land allocation is out of reach of many farmers, since they have yet to achieve food security with the reduced land area of maize. This cropping design is still aspirational, despite the evidence farmers have seen from field trials. The poorer farmers have, however, embraced the introduction of the doubled-up legume technology in addition to the traditional maize/pigeonpea intercropping system, making it a potentially viable intensification pathway on small farms.

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