Sustainable Intensification Practices for Smallholder Farmers in Zambia

A Farmer's Manual

SIFAZ

Sustainable Intensification of Smallholder Farming Systems in Zambia

This project is funded by the European Union

Food and Agriculture Organization of the United Nations

CIMMYT

International Maize and Wheat Improvement Center

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The International Maize and Wheat Improvement Center – is the global leader in publicly-funded maize and wheat research and related farming systems. Headquartered near Mexico City, CIMMYT works with hundreds of partners throughout the developing world to sustainably increase the productivity of maize and wheat cropping systems, thus improving global food security and reducing poverty. CIMMYT is a member of the CGIAR System and leads the CGIAR Research Programs on Maize and Wheat and the Excellence in Breeding Platform. The Center receives support from national governments, foundations, development banks and other public and private agencies.

Contents

Preface iv
1. Introduction 1
2. Implementing crop diversification 2
2.1 Cereal and legume selection 2
2.2 Crop calendar 3
3. Strip intercropping 5
3.1 Proposed novel intercropping strategies 5
3.2 Planting configurations in double-row strip cropping systems 5
3.3 Maize-legume four-row strip cropping 7
4. Doubled-up legume systems 9
4.1 Doubled-up legume systems under Conservation Agriculture 9
4.2 Common doubled-up legume systems in Zambia 9
4.3 Advantages of and challenges with doubled-up legume systems 10
4.4 Implementing doubled-up legume systems in the field 11
4.5 Establishing doubled-up legume system under Conservation Agriculture 11
5. Intensification with agro-forestry species 14
6. Legume flat planting and double cropping 17
6.1 Legume flat planting 17
6.2 Legume double cropping 17
7. Cassava intensification with legumes 19
8. Permanent raised beds 21
9. Choosing cereal and legume varieties 24
9.1 Maize variety choice 24
9.2 Sorghum and millet varieties 25
9.3 Choosing legume varieties 25
10. Land preparation 28
10.1 Conventional tillage 28
10.2 Conservation Agriculture 28
11. Timely planting and planting depth 30
11.1 Timely planting and use of climate information 30
11.2 Planting depths and when to plant in rainfed systems 30
12. Weed control strategies 31
12.1 When to control weeds 31
12.2 How to control weeds 32
13. Soil Fertility Management 34
13.1 Use of Manure 34
13.2 Basal Fertilizer 34
13.3 Topdressing Fertilizer 35
14. Pest and Disease Control 36
15. Harvesting and Post-harvest Management 37
16. Input and output marketing 39
Seed quality and access 39
Key factors to consider when purchasing quality maize and legume seed 39
Understanding smallholder participation in maize and legume markets 39
Potential solutions for integrating smallholders into the markets 40

Preface

This manual is written as a guide for use by farmers intending to sustainably intensify their smallholder cropping systems involving food and cash crops such as cassava, maize, sorghum and millet as well as common beans, cowpea, groundnut, pigeon pea, soybean and agro-forestry species, amongst others. The manual intends to enable farmers to increase their productivity while achieving food security and nutrition. It provides general guidelines for farmers based on the experiences of various sustainable intensification projects in Southern Africa and more specifically, to the Sustainable intensification of Smallholder Farming Systems (SIFAZ) Project in Zambia. This manual is particularly applicable to smallholder farms that share the same agro-ecological conditions as the mid-altitude mixed-maize production areas found in Southern Africa.

1

Introduction

Staple crops such as cassava, maize, millet and sorghum play a critical role in ensuring the food security and nutrition for millions of people in Southern Africa. While these staple crops are a major source of carbohydrates, legumes such as soybean, groundnut, common beans, cowpea and pigeon pea give Southern Africans an affordable and more diversified source of proteins and vitamins.

In the case of Zambia, significant growth in food demand due to a rapidly expanding population will require a considerable increase in the production of these staple crops and the mitigation of any adverse environmental impacts. A practical approach towards increasing farm productivity, maintaining healthy crops and fertile soils and maximizing resource use efficiency is the sustainable intensification of cropping systems. This approach utilizes various forms of crop diversification, including intercropping; relay cropping; double cropping and multiple cropping as well as crop rotations.

Growing several types of crop species on the same plot of land ensures an increased household intake of dietary carbohydrates, proteins and vitamins and improves soil fertility through symbiotic nitrogen fixation from legume crops. This benefits humans as well as livestock through the provision of higher quality feed. Growing a crop surplus helps farmers improve their food security and nutrition and results in increased incomes and enhanced livelihoods.

This manual details the technical requirements required to implement sustainable intensification practices, from land preparation to harvest. The ***Sustainable intensification of Smallholder Farming Systems (SIFAZ) Project in Zambia*** project and similar projects in Southern Africa have explored a range of technologies that integrate various crop diversification strategies with Conservation Agriculture (CA). The primary objective of this manual is to enhance the resilience of farmers to climate change-induced hazards and a degrading soil resource base. Crops grown under sustainable intensification practices are able to withstand moderate to severe moisture stress more effectively, leading to higher yield results when conventional systems are failing. Furthermore, increased crop diversification in such systems reduce the risk of complete crop failure due to drought, excessive rainfall, pests and disease attacks. Increased crop diversification strategies also help build and maintain the natural resource base.

This manual is divided into chapters that describe sustainable intensification practices in detail, followed by common good agriculture practices that are important for and universally applicable to these systems. With this practical guide, we hope that farmers will be able to apply these systems independently, harnessing the benefits that each system can offer.

2

Implementing crop diversification

Common to most sustainable intensification practices is the element of diversification. In Southern Africa, the most widely practiced strategies of crop diversification are crop rotation, intercropping and relay cropping. Critical to crop diversification is insight into the suitability of crops for each cropping system. Use of innovative planting configurations can be an effective way for two crops to share the same growing space without compromising yields. This manual provides information on possible plant configurations that are successfully being utilized and promoted by the SIFAZ project.

2.1 Cereal and legume selection

The selection of cereals and legumes most suitable for intercropping and rotation depends on farmer needs (food security or cash crops), climatic conditions and soil types (**Table 2.1**).

In Zambia, maize is the predominant crop grown. It thrives on well-drained soils with moderate- to -high fertility in sub-humid to humid climates and rainfalls of about 600 to 1400 mm. Short season and drought-tolerant maize is also widely grown in

Table 2.1 Typical climatic and soil requirements for various cereals, legumes and cassava.

Crop type	Crop	Seasonal rainfall	Optimum soil characteristics	Temperature	Growing period	Remarks
Cereals	Maize	600-1400	Well drained fertile soil, pH 5.5-6.5	18-32°C	80-150 days	The most important staple crop in southern Africa New drought tolerant varieties available
	Sorghum	300-800	Well drained, deep loamy textured soils, pH 5.5-8.5	25-30°C	110-130 days	Drought tolerant and suitable for semi-arid conditions
	Finger Millet	500-1000	Fertile and well drained soils, pH 5.0-8.2	11-27°C	105-150 days	Drought tolerant and suitable for semi-arid conditions
	Pearl millet	250-700	Light well drained loamy soils, and low pH (4-5) tolerant	23-30°C	70-100 days	Susceptible to waterlogging but can tolerate infertile soils
Legumes	Common beans	>1000	Well drained loamy soils 5.8 to 6.5	18-24°C	80-115 days	Grows better in cooler climates at higher altitudes
	Cowpea	400-900	Well-drained, sandy loam to clay loam soils 5.8-6.5	20-30°C	80-120 days	Susceptible to aphid attack and needs frequent use of pesticides
	Ground-nut	500-1200	Well-drained, light sandy loams, pH 6.0-7.0	18-33°C	100-180 days	Heavy soils make harvesting difficult. Calcium requirement is needed to achieve good yields
	Soybeans	500-1200	Deep well drained medium to heavy textured soils with high fertility, pH 6.0-6.5	15-25°C	110-140 days	Always inoculate with rhizobia if soybeans are not promiscuous to achieve a good yield
	Pigeon pea	600-1400	Well drained light or heavy textured soils, pH 6.0-7.0	18-30°C	120-180 days	Deep rooted and drought tolerant
	Cassava	500-1600	Well drained sandy to clay soils with tolerance to low pH (3.6-5)	18-30°C	540-720 days	Grows well on poor infertile soils where other crops fail

semi-arid to arid regions with rainfalls below 600 mm. High rainfall areas (>1000 mm per season) and hot environments result in faster maize crop growth and allow farmers to plant in higher crop density and fertilizer application rates. Low plant density is recommended for areas with lower rainfall (<600 mm).

Growing legumes is also dependent on reliable rainfalls that do not exceed threshold levels as the nodulation of legumes is negatively affected by excessive soil moisture. In Zambia, legumes grow best in moderate rainfall conditions as pest and disease pressure is lower. Sufficient rainfalls are necessary when legumes are grown as intercrops due to the increased competition for moisture between different crops.

2.2 Crop calendar

The crop calendar (**Table 2.2**) provides guidance on cereal and legume planting, sowing as well as harvesting periods in target areas. The cropping season normally begins with the first effective rains (defined as 30-50 mm of rainfall over 1-3 days) around mid-November. These rains are considered a reliable planting signal.

Table 2.2 A typical crop calendar for maize, legumes and cassava in Zambia.

Crop	Activity	Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun
	Rainfall												
Maize, Sorghum and Millet	Land preparation												
	Planting												
	Weeding												
	Harvesting												
Cowpea	Land preparation												
	Planting												
	Weeding												
	Harvesting												
Groundnuts	Land preparation												
	Planting												
	Weeding												
	Harvesting												
Soybeans	Land preparation												
	Planting												
	Weeding												
	Harvesting												
Pigeonpea	Land preparation												
	Planting												
	Weeding												
	Harvesting												
Common beans	Land preparation												
	Planting												
	Weeding												
	Harvesting												
Cassava	Land preparation												
	Planting												
	Weeding												
	Harvesting	after 18-24 months											

One key consideration for successful farming in Zambia is that crops are established and mature within the rainy season. Defining a suitable agro-ecology for each crop depends on the onset and end of the rainy season which determine the length of the crop growing period.

However, crops that grow on residual moisture such as pigeon pea, can be relay cropped so that the peak water demand period for maize does not coincide with that of pigeon pea. In Southern Africa, pigeon pea matures after maize and can be harvested as late as July and/or August if livestock such as goats and/or cattle are prevented from feeding on the crop. The following chapters provide detailed descriptions of each of the recommended cropping technologies applied under sustainable intensification..

3

Strip intercropping

Traditionally, farmers in Southern Africa have always considered the mixing of crops to be a useful and effective way of diversifying food sources, particularly in conditions where land is limited. The crop mix must be compatible and beneficial to each other. As an example, when maize is intercropped with groundnut, the groundnut fixes nitrogen into the soil through biological nitrogen fixation which then becomes available to the maize. The groundnut can then access other nutrients that have been applied to the maize, such as phosphorus and potassium.

Depending on planting timing, soil type and rainfall conditions, tall growing maize crops can often overshadow groundnut or other legumes, if planted in alternating rows. This can result in depressed legume but also maize yields as two crops instead of one often lead to increased crop competition. Early planted cowpea can also lead to the suppression of maize when the sequencing is done wrong (e.g., planting both crops on the same day may lead to complete suppression of maize therefore a delay of cowpea planting by 7-10 days is recommended). Access to light and sunshine is a key factor for companion crops to co-exist.

3.1 Proposed novel intercropping strategies

a) ***Double-row strip cropping:*** This system reduces the plant spacing of maize rows to open up space for legumes to grow.

b) ***Four-row strip cropping:*** Similar to double-row strip cropping above, four rows of maize alternate with four rows of a legume. However, the inter-row spacing of maize is reduced from the usual 90 cm to 45 cm. This narrowing and reduction in size increases growing space for four rows of legumes.

3.2 Planting configurations in double-row strip cropping systems

In double-row strip cropping systems, the plant spacing of maize is reduced from 90 cm row spacing to 50 cm, with an in-row spacing of 25 cm. This gives way to a space of 130 cm for the planting of legumes (see schematic below). Either three (cowpea, groundnut and beans) or two (pigeon pea) legume rows can now be planted in this 130 cm space, allowing them to proliferate (**Figure 3.1**). The planting rows can either be created with a dibble stick, an animal traction rip line or direct seeding, or with tractor-powered rippers or direct seeders, following the CA principle of no-tillage (**see chapter 10.2**).

For three legume row strip cropping systems, rows should be spaced 35 cm from each other and with 30 cm left on either side from the last row of legumes to the next row of maize. Ensuring these spacings are maintained is of critical importance. A slight deviation from this system could involve two rows of cereals followed by two rows of legumes with a spacing of 45cm between each other. Both systems maintain the same plant population per hectare whereas double-row strip cropping systems increase the legume population by one third. In the following cropping season, the two maize rows will be placed between the three legume rows and the legume rows will be planted on top of the old maize rows with the same planting pattern of 50 cm row spacing for the maize and 130 cm row spacing for the legumes. The maize will not be seeded on top of the legume row as the space that the legume occupied in the previous year was larger (130 cm) than the maize row (50 cm).

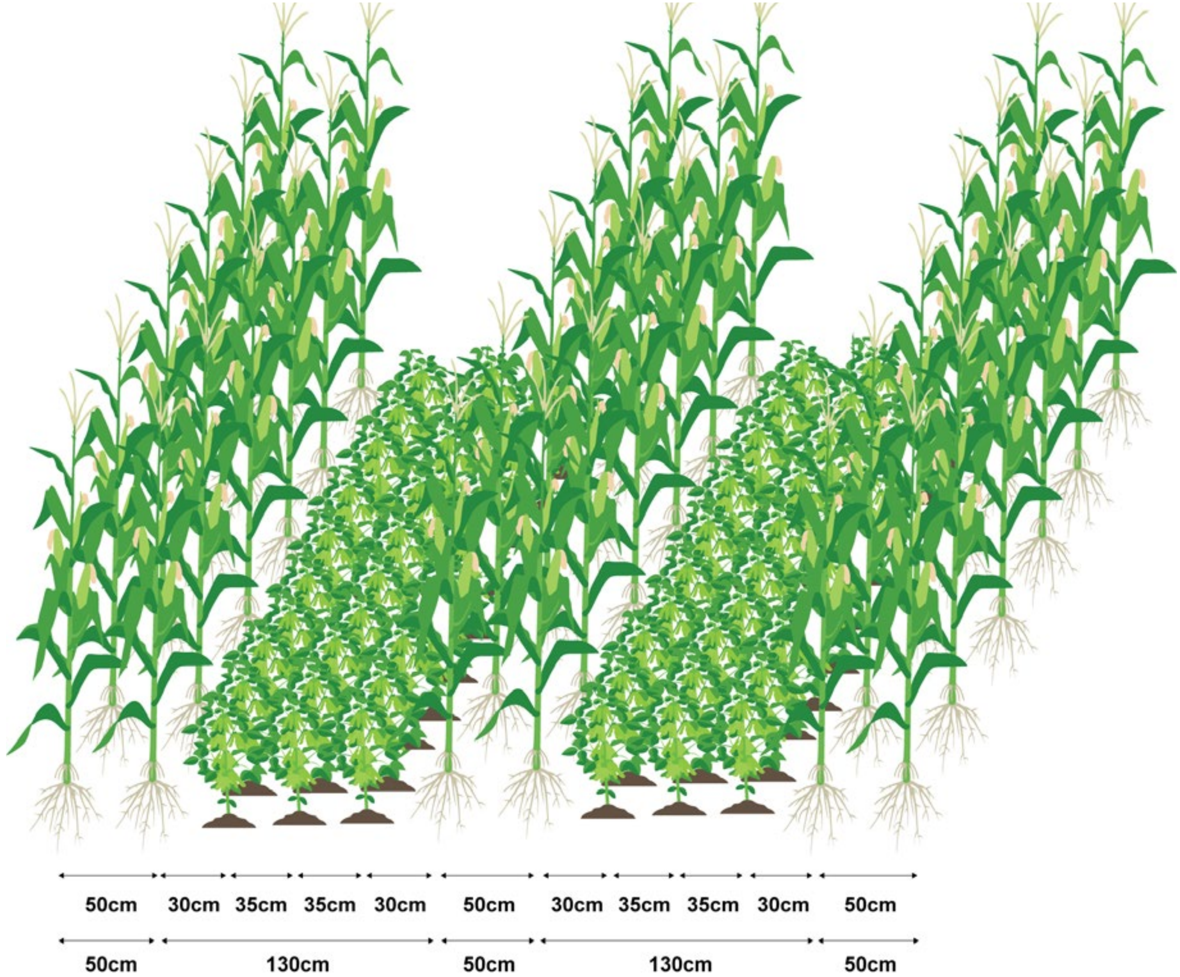


Figure 3.1 Planting configuration for double-row strip cropping with maize and soybeans.

Table 3.1 Advantages of double-row strip cropping.

Advantages
• Maize plant population is not compromised as cereal and legume crops occupy the same space that would have been occupied by a sole crop.
• Use of a two-wheel tractor to plant legumes and maize rows becomes possible as they can fit into the 130 cm growing space of the legume. The operator needs to seed the maize first and following its emergence, seed the legumes.
• Improves access to light for short-growing legume crops as compared to conventional intercropping, resulting in improved crop development and increased yields.
• Overall productivity of the system is increased as two crops are harvested on the same piece of land instead of one without major yield penalty.

Table 3.2 Challenges associated with double-row strip cropping.

Challenges
• Increases competition for nutrients and moisture (especially under drought conditions) as the total density of crops is higher in this system than in the sole crop planting.
• Requires careful consideration of planting time for each crop in order to ensure that the legume is not overshadowed by the tall growing maize.
• Requires careful consideration of chemical weed control as the two crops require different types of herbicides.

Picture 3.1. Two-row (left) and four-row strip cropping (right) in Zambia.

3.3 Maize-legume four-row strip cropping

For maize four-row strip cropping, a plant space of 360 cm is divided by four rows of maize (180 cm) and four rows of legume (180 cm). The principle is the same as double row strip cropping systems whereby the cereal population is maintained but row spacing is reduced to create space for the legumes. For cereals and legumes, plant spacing is reduced to 45 cm, resulting in four-row strips that occupy the 180 cm space. The in-row spacing of both the maize and legumes is maintained and follows common recommendations of in-row plant spacing (**Table 2.1**). This plant configuration is illustrated in **Figure 3.2.** This system requires that the cereal and legume strips are placed in alternating positions each year, mimicking a full rotation cycle.

Table 3.3 Advantages with four-row strip cropping.

Advantages
• Ensures more space for the legume crop to access sunshine due to wider rows.
• Minimizes direct competition between the legume and the cereal crop.
• Reduces soil erosion.
• Allows for mechanized ripping or planting if strips are well marked.

Table 3.4 Things to worry about with four-row strip cropping.

Challenges
• Maize is more densely planted as compared to sole crop systems.
• Requires precise marking of strips prior to planting.
• Is not suitable for conventional ridge/furrow systems as inter-row spacing is restricted to 45 cm.

3.4 Recommended companion legume crops to staple cereal crops

In Southern Africa, cereals such as maize and sorghum are the subregion's most important staple crops , followed by legumes as secondary crops. Maize and sorghum should therefore be planted with the same number of plants per ha as planting a sole crop. For maize, it is recommended that the following legume crops be grown as companion crops in double-row and four-row strip cropping systems, with specified row spacings (**Table 3.5**).

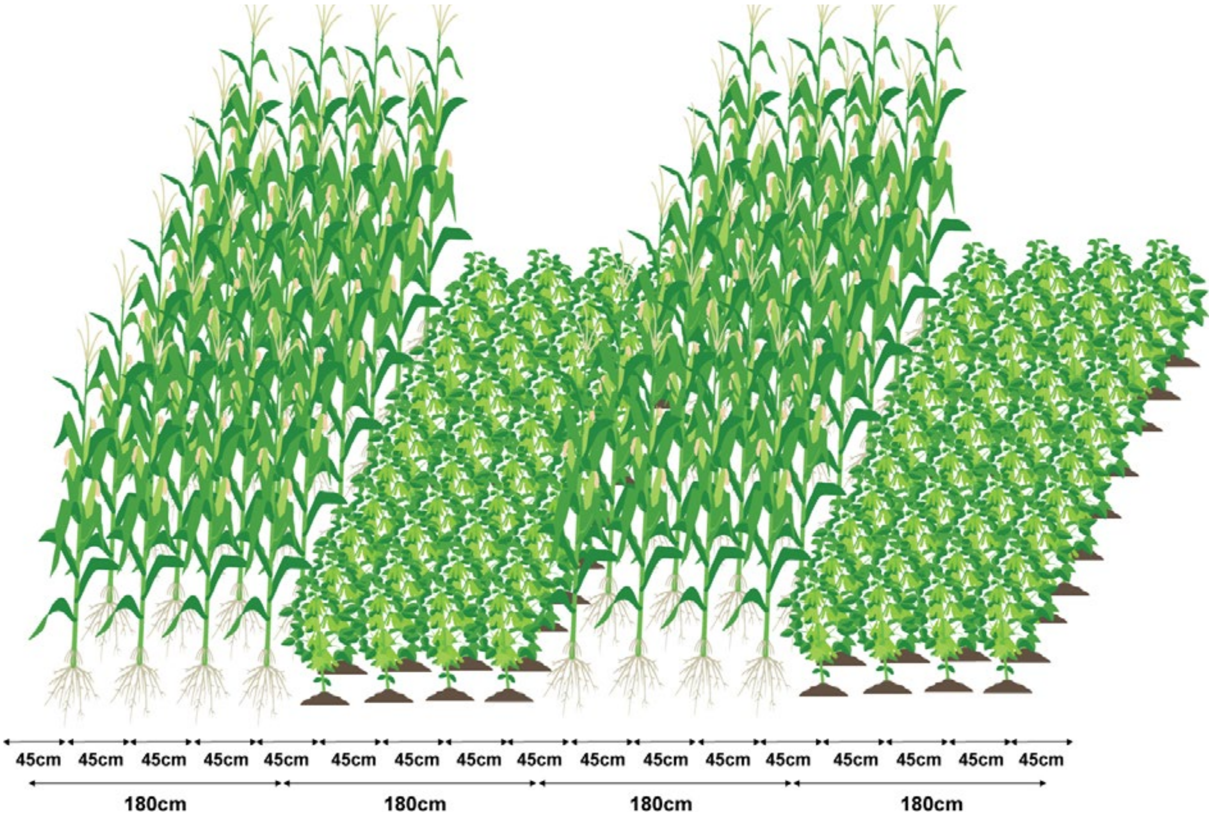


Figure 3.2 Plant configuration for a four-row strip cropping system.

Table 3.5 Recommended row spacings and legume crops intercropped with maize.

Recommended legumes	Double-row strip cropping (2 rows maize/2 or 3 rows legumes)	Four-row strip cropping 4 rows maize/4 rows legume
Cowpea	35 cm x 12 cm	45 cm x 10 cm
Common beans	35 cm x 15 cm	45 cm x 15 cm
Groundnut	35 cm x 30 cm	45 cm x 30 cm
Soyabeans	35 cm x 5 cm	45 cm x 5 cm
Pigeon pea	45 cm x 100 cm	N/A
Velvet bean	45 cm x 30 cm	45 cm x 30 cm

4

Doubled-up legume systems

4.1 Doubled-up legume systems under Conservation Agriculture

A major principle of sustainable intensification is the increase of crop yields per unit land area, without negative effects on the environment. This is achieved by intercropping legumes in a maize stand as well as during the legume phase, where several legumes are strategically combined. This novel cropping system is called a "doubled-up legume system". Increasing the number of legumes and combining them, requires a good understanding of their growth habits, architecture, competition and allelopathy, making careful selection of companion crops essential. Doubled-up legume systems in smallholder farmers' fields are usually practiced in rotation with cereals such as maize or sorghum and require sufficient land area to implement a full rotational system.

4.2 Common doubled-up legume systems in Zambia

Doubled-up legume systems involving groundnut and pigeon pea are a complementary combination as groundnut solely exploits soil surface areas and undergo fast maturation, as opposed to pigeon pea which matures slowly, resulting in less competition within this system (**Figure 4.1**). Pigeon pea matures at least 2-3 months after the groundnut and the system usually provides an increase in overall grain yield from both crops. Pigeon pea also adds a large amount of slow decomposing biomass as well as nitrogen-rich leaves and stems, which can be used partially as surface mulch or firewood. This benefits the entire cropping system and the household.

Doubled-up legume systems with soybean or cowpea and pigeon pea are more challenging

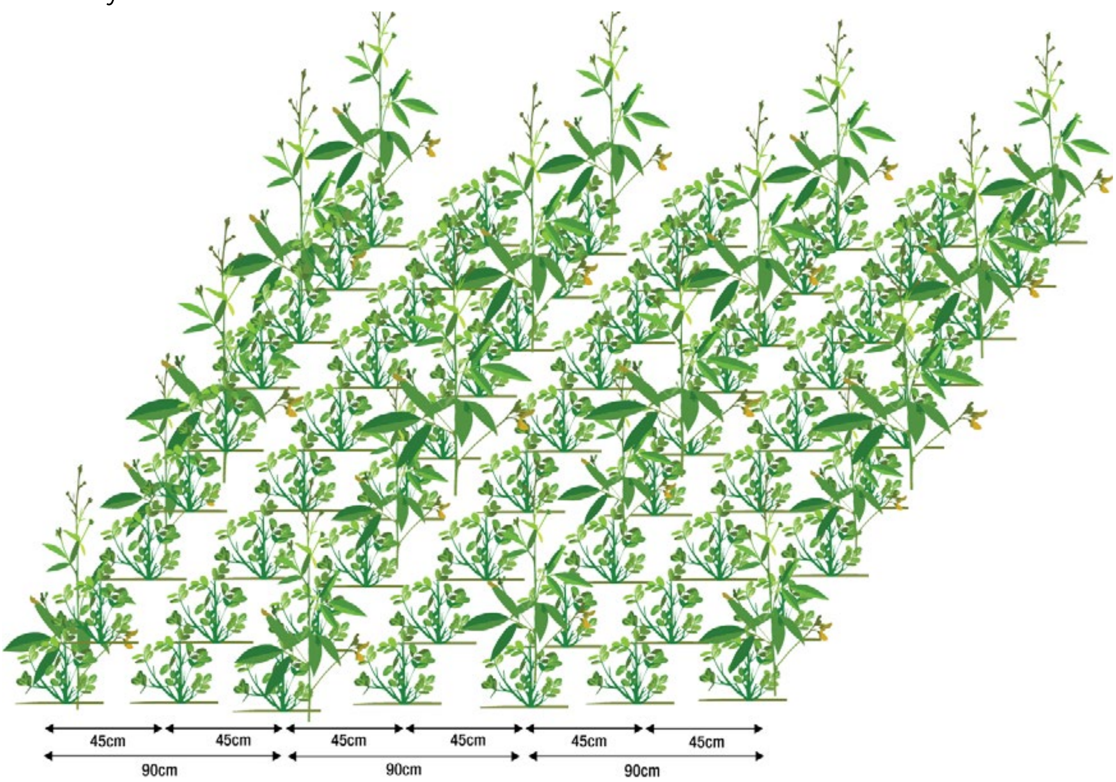


Figure 4.1 Plant configuration in a doubled-up legume system.

to manage as both soybean and cowpea are vigorous growers, resulting in increased competition. As such, this system requires careful planning and sequencing. The most effective strategy to manage this system is to intercrop pigeon pea with maize in the first year followed by ratooning the same standing pigeon pea in the second season where soybeans or cowpea are grown (in the doubled-up system). This gives the pigeon pea a major initial advantage in the legume phase and provides the desired outcome of increasing the overall productivity per land area (**Figure 4.1**). Planting pigeon pea and soybean/groundnut at the same time will lead to suffocation of the pigeon pea.

4.3 Advantages of and challenges with doubled-up legume systems

Doubled-up legumes grown under conservation agriculture are new systems for smallholder farmers in Zambia and require demonstration and careful training.

Table 4.1 Advantages of doubled-up legume systems.

Advantages
• Increases crop yields and total system's productivity when two legume crops are grown instead of one. This benefit is especially prevalent if grown under no-till Conservation Agriculture systems.
• Enhances soil health and structure through macro and micro fauna diversity.
• Improves water infiltration and soil moisture.
• Increases soil cover and minimizes water run-off and soil erosion.
• Enriches soil fertility through legume nitrogen fixation, which can be substantial, allowing for mineral fertilizer reductions.
• Suppresses pests and diseases by breaking the life cycle of attacking pests and weeds.
• Increases adaptation and mitigation to the effects of climate change through carbon sequestration in soils.
• Diversifies food sources, reduces risks of crop failure and increases food security and nutrition.

Table 4.2 Challenges associated with doubled-up legume systems.

Challenges
• Germination of pigeon pea can be a major challenge and requires seeding 5-7 seeds to achieve a decent plant population.
• Goats/cattle may attack standing pigeon pea crops, thereby reducing the harvest of grains. To mitigate this, short-to-medium maturing varieties are recommended.
• Competition between different legume species require careful planning of companion crops and sequencing of planting dates.
• Low adoption of legume systems in general is currently prevalent due to limited availability and high cost of legume seeds. This requires an early seed search for various legume species and varieties.
• Potential risk of crop yield losses during the legume phase if pods are attacked by legume-specific pests. This requires integrated pest control measures.
• Potentially challenging marketing of specific legume crops if crops are unfamiliar and market prices are volatile (as was the case for pigeon pea in the past).

4.4 Implementing doubled-up legume systems in the field

Choosing a doubled up-legume rotation depends on:

1. The type of crops most suitable for the legume phase as well as the rotation phase.
2. The amount of land available to accommodate the rotational system. Many smallholders who own less than 1 ha of land prefer intercropping of cereal and legumes every year to meet dietary household needs, instead of having full doubled-up legume rotations.
3. The timing of cereal and legume planting is important, especially in the legume phase where proper arrangement and/or sequencing helps ensure that competition is reduced and overall productivity is high.

4.5 Establishing doubled-up legume system under Conservation Agriculture

The choice of crops in doubled-up legume systems largely depends on market prices and the availability of legume seeds.

A doubled-up legume system is comprised of the legume phase, where two legumes are grown, and a rotational phase, where cereals are normally grown after the legumes in a full rotation. Maize follows normal plant spacing and benefits from the preceding legume phase. In some instances, the cereal must be intercropped with pigeon pea, as described below.

a) Maize-groundnut/pigeon pea doubled-up legume system

In this system, pigeon pea is planted with the groundnut at the time of seeding during the legume phase (**Picture 4.1, left**). In CA systems where no ridges are made, groundnut is planted in 45 cm rows and pigeon peas planted alongside every second groundnut row (with a suggested 90 cm row spacing). Row spacings for groundnut are normally 20-30 cm whereas pigeon pea is seeded at 50 cm (one plant) or 75-100 cm (two plants) in-row spacing. Seeding can be done in rip lines or small planting holes (created by a hoe). Greater information on row and in-row spacing is detailed in **Table 2** below.

In Malawi, farmers have grown pigeon pea in densely populated hedgerows spaced 3 m apart and this has led to relatively high yields with no effect on groundnut yields in the doubled-up legume systems (**Picture 4.1, right**).

As pigeon pea is an extremely poor germinator, it is important to plant 5-7 seeds of pigeon pea and to thin seedlings to 1-2 plants per station once germinated. It is also crucial to plant the pigeon pea and groundnut on the same day to avoid any overshadowing of


Picture 4.1 Doubled-up legume systems involving groundnuts and pigeon pea planted within rows (left) or as hedgerows (right).

the pigeon pea by the groundnut, due to the groundnuts' fast growth. Typically, groundnut will emerge, grow and mature whereas pigeon pea will lag behind and mature 2-3 months after the legume.

At harvest time, groundnuts can be lifted with a hoe, shovel, spade or pulled out of the soil with pigeon pea left growing. Once the pigeon pea is ready for harvesting, their pods must be stripped off their branches. When maize is planted in the following cropping season as a rotational crop, the pigeon pea can be ratooned or uprooted and replanted and biomass laid on the soil surface. This will significantly increase groundcover and carbon cycling. Ratooning is the practice of cutting off above-ground biomass and leaving roots and growing shoots and allowing new shoots to continue growing from the remaining surface stumps. This practice allows short growing crops to access sunlight and means the grower does not need to use fresh seed. Portions of the pigeon pea stems may also be used as firewood. Maize can then be grown as sole crop or alternatively with an intercrop of pigeon pea, until the legume phase resumes with a new groundnut/pigeon pea doubled-up legume phase..

b) Maize-soybean/pigeon pea doubled up legume system

Unlike groundnut, soybean is more competitive in its initial growth stage and can potentially suffocate the pigeon pea if planted at the same time as the soybean. Several attempts have been made to overcome this challenge and research results show that sequential implementation of this specific doubled-up legume system is required.

Pigeon pea may be established in the cereal phase as this would be the sole method to properly establish a pigeon pea crop. During the legume phase, the pigeon pea must be ratooned while soybeans are planted between the ratooned pigeon pea. This will give the pigeon pea a head- start and allow for the establishment of both crops without suffocation. Alternatively, a row of soybean could be omitted where pigeon pea rows are established, however this could lead to massive yield penalties of soybean, which should be avoided. Planting pigeon pea 3 - 4 weeks earlier than the legume is another alternative, but is only applicable to fast-growing legumes (e.g. beans or cowpea) and is not applicable to soybean doubled-up legume systems due to soybean sensitivity to planting delays. Soybean is usually planted in 45 cm rows with an in-row spacing of 5 cm between seeds, as high population is desirable (**Table 3.1 above**). Following the maize row, pigeon peas are planted with a spacing of 90 cm between rows and 50 cm (one plant per station) to 75-100 cm (two plants per station) of in-row spacing, as less densely spaced pigeon pea is often more beneficial. Maize planting should be established based on its normal spacing and population requirements, consistent with its specific agro-ecology and should not change. As described above, the pigeon pea should be re-established by ratooning the remaining crop and spreading it on the soil surface.

c) Maize-cowpea/pigeon pea doubled-up legume system

Growing cowpea in a doubled-up legume system is more challenging, especially if spreading varieties of cowpea are used (**Picture 4.2, left**). As in the soybean system, it is recommended to establish the pigeon pea first during the maize phase, and subsequently ratooning it during the cowpea seeding phase. This results in a well-established pigeon pea and prevents suffocation. Due to the fast-growing maturity of cowpea, it is often possible to grow a second crop of cowpea in the same year, thereby increasing sustainable intensification outcomes even further. Cowpea should be planted at a row spacing of 45 cm and an in-row spacing of 10 cm (**Table 3.1 above**). However, some spreading cowpea varieties can be planted with wider spacing. Following the maize, the pigeon pea is planted with a row spacing of 90 cm between rows and with an in-row spacing of 50 cm (one plant) to 75-100 cm two plants), resulting in less densely-spaced planting that is more beneficial (**Picture 4.2, right**)..


Picture 4.2 Doubled-up legume systems of cowpea and ratooned pigeon pea (left) and ratooned pigeon pea with maize (right).

Table 4.3 Recommended plant configuration arrangements for different legumes intercropped with maize.

Crops	Cereal phase	Doubled-up legume phase
Maize	90ncm x 25cm	
Pigeon pea	90 cm x 50 (100)	90 cm x 50 cm (75-100 cm)
Cowpea		45 cm x 10-20 cm
Groundnut		45 cm x 20-30 cm
Soyabeans		45 cm x 5 cm

5

Intensification with agro-forestry species

To intensify current maize-based systems even further while providing additional benefits to the soil and to farmer households, the inclusion of agro-forestry species has been explored and successfully implemented. Trees provide a range of benefits to the farming system, ranging from the addition of nutrient-rich leaves, shade and a positive microclimate, to ecosystem services and the availability of firewood. However, the addition of trees within a landscape can also cause competition between the tree and the existing main crop, potentially resulting in additional labour to ensure successful coexistence. The sustainable intensification initiatives implemented in Zambia used *Gliricidia sepium,* a leguminous tree species, well-adapted to the environment for their sustainable intensification practices. One important requirement of this system is to grow the trees in hedge rows or as dispersed trees for the leaves to be utilized in a "chop-and-drop" manner. This limits the need for labour in transporting biomass from one plot to the other. The spatial arrangement also aims at keeping competition as low as possible while reaping the benefits of agro-forestry species.

a) Maize-Gliricidia hedge-row system

This system has previously been developed and perfected by the Community Market for Conservation (COMACO) in Eastern Zambia and has already led to widespread adoption. Maize-legume rotations are planted with normal plant populations with 90 cm between rows and 25 cm in-row (maize) or row-spacing of 45 cm (legumes). In addition, hedgerows of *Gliricidia* trees are planted in 5 m rows with 1 m in row spacing (**Figure 5.1**, **Picture 5.1, left**). Establishing the first set of trees in the

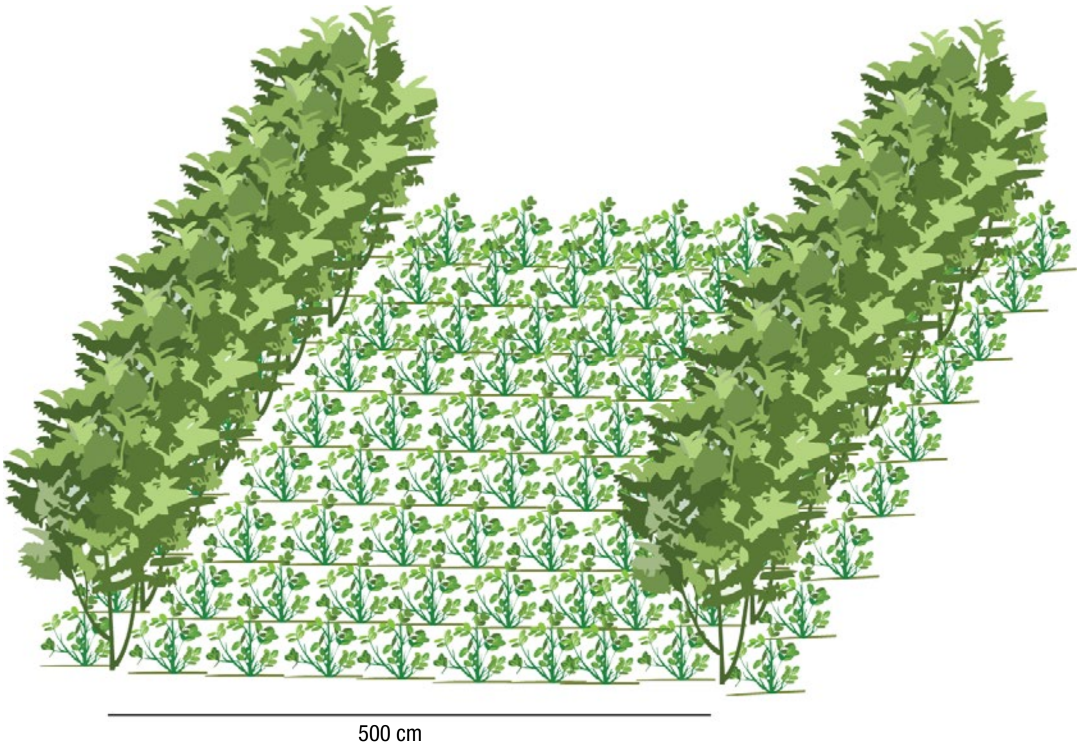


Figure 5.1 Maize-*Gliricidia* hedgerow system.

first cropping season can be challenging and may require gap-filling and re-planting. Once the hedgerows are established, the trees can be pruned yearly to maintain subtle growth without causing too much competition with the maize. Pruning time is essential as the tree's nitrogen-rich green leaves can benefit the soil as well as the plants growing in it. Maize is a typical companion crop in a *Gliricidia* cropping system and requires the largest dose of nitrogen between 4-7 weeks after planting. Pruning and green manuring of Gliricidia leaves should therefore be done just after maize emergence to ensure that the nitrogen from the decomposing leaves is available when the maize needs it. The *Gliricidia* trees can either be pruned by stripping the leaves off their branches and spreading them across planting areas or by pruning whole branches and placing them next to the maize plants.

b) Maize-Gliricidia disbursed shading system

Unlike the *Gliricidia* hedgerows, the disbursed shading system aims to develop larger *Gliricidia* trees that can provide shade, decrease competition and provide planting areas with some green leaves after yearly pruning. (**Picture 5.1, right**). Under this system, Gliricidia trees are planted at a spacing of 5 m between rows and 10 m in-row which lead to a less densely populated tree population. Unlike the hedge row system, Gliricidia plants are pruned to become large trees with a larger canopy. This system is particularly suited to areas characterized by heat stress. Moderating the temperature can significantly affect the ambient temperature with positive side effects on companion crops which grow better when temperatures are lower.


Picture 5.1 *Gliricidia* hedgerow (left) and a disbursed shading system (right).

Table 5.1 Advantages of *Gliricidia* systems.

Advantages
• Increases biomass availability from leaves and branches adding to groundcover.
• Nitrogen-rich leaves compliment mineral fertilizer.
• 'Chop-and-drop' method help reduce farm labour.
• *Gliricidia* trees help regulate moderate to high temperatures by providing shade.
• Hedgerows and disbursed shading helps minimize competition.
• If seedlings are unavailable, *Gliricidia* plants can also be propagated with branches.
• Cattle and goats feed on leaves as fodder, providing extra feed

Table 5.2 Challenges associated with *Gliricidia* systems.

Challenges
• *Gliricidia* trees require time to properly establish. • Risk of termite attacks on woody parts. • Viability of seedlings may be problematic as they require proper establishment in the first cropping season and are easier to establish during the legume phase than the maize phase. • Pruning requires additional labour which can be limiting to system replication. • Farmers often hesitant to grow non-food crops if the benefits of soil fertility are not well explained.

6

Legume flat planting and double cropping

6.1 Legume flat planting

Farmers who traditionally use ridge and furrow systems or who plant legume crops randomly without rows often experience low yields due to low plant populations. A simple method to increase crop yields is to avoid restrictive ridge and furrow systems that limit plant populations and instead, plant crops on the flat, in rows containing an optimal plant population (**Picture 6.1**).

Legumes such as groundnut and common beans can be flat planted in rows spaced between 37.5 cm to 45 cm in order to rapidly achieve a close canopy. This will require planting lines created by either a ripper or hoe. Under this system, crops are grown using a higher plant population and by enabling a close canopy. The increased plant population allows farmers to harvest almost double the yield than legume crops planted on ridges.

6.2 Legume double cropping

In areas where moisture is abundant and the cropping season lasts until April/May as is common in Northern Zambia, the moisture allows for growing two legumes in a season with one crop following the other. In these conditions, it is possible to grow common beans and cowpea twice in a season. This requires early seeding in November, followed by another replanting in February for a second crop to be harvested in May. Residual moisture ensures that the legumes will still mature. Double cropping of common beans and short season cowpea has effectively

Table 6.1 Advantages of legume flat planting.

Advantages
• Ensures a more uniform and often doubled plant population.
• Creates a more densely populated soil area that smothers weeds and reduces soil erosion.
• Reduces rosette disease in groundnut.
• Weeds are easier to control when crops are planted in rows.
• Harvesting is easier for row crops than haphazardly planted crops.
• Spraying of chemicals is simplified in row crops.

Table 6.2 Challenges associated with legume flat planting.

Challenges
• Requires more careful planning and implementation.
• Requires the introduction of rip lines or hoe lines for planting.
• Harvesting of groundnut may be slightly challenging if soil is hard and crops are not planted on ridges.

Picture 6.1 Legume flat planting offers additional growing space for groundnut to proliferate (right) unlike in a conventional ridge system that restricts growth to 75 cm rows (left).

been implemented and it has been shown that the growing of a second legume can increase the income and nutrition of the household by almost double. Crops such as common beans and cowpea grow well in residual moisture conditions and prove to be good candidate crops for double cropping.

The double cropping of beans is a common practice in Northern Zambia. For maize crops, the residual moisture that is present following maize maturation is often wasted, leading to considerable late season weed infestation. This often causes subsequent weeding challenges in the next season.

Table 6.3 Advantages of legume double-cropping.

Advantages
• Double cropping increases the output per unit area without the need for additional inputs.
• The second crop is exposed to fewer pest and disease pressures.
• Increases household income and nutrition from the same plot of land.
• Improves soil fertility, groundcover and biomass input into the system.

Table 6.3 Challenges associated with legume double-cropping.

Challenges
• Requires timely seeding by November to avoid late planting which could compromise the planting of the second crop.
• Crops require timely harvesting and replanting to ensure that the second crop can successfully mature.
• Without careful management, the first crop can experience mould or re-germination in the field.
• Short-to-medium maturing varieties are required to ensure that the first crop is harvested quickly.
• Drying of the first crop during the February rains poses a challenge for smallholders without sheds or drying facilities.
• In short rainy seasons, the second crop can run out of moisture. Double cropping is best practiced in high rainfall regions with a longer growing season.

7

Cassava intensification with legumes

Cassava is grown throughout the developing world on flat land with propagation sticks planted in tilled soil. Using improved varieties, the crop can be harvested after 18-20 months. In Zambia, cassava is usually planted on ridges, which increase the labour for planting and causes soil disturbance and erosion. Planting on ridges poses a limitation for the way other crops can be planted with cassava as ridges are only available for planting companion crops, with furrows left bare.

Cassava planting under Conservation Agriculture aims at planting cassava sticks on flat land without ridging, into a small planting hole created by a stick or hoe. This creates an opportunity for legume crop planting within the first year of cassava establishment. Cowpea, groundnut and beans have successfully grown with cassava in high rainfall areas under no-tillage. This has resulted in higher cassava yields during the harvest year. In this system, cassava is planted with a spacing of 1 m x 1 m where spacing along and in-between the cassava rows is filled with legumes at normal plant spacing (**Figure 7.1**). Initially, there is little shading from the cassava and the legumes can proliferate and produce higher yields. In the second cropping season, the cassava can benefit from the additional nitrogen supplied by the legumes, however legumes can no longer be grown due to the shading effect of the cassava..

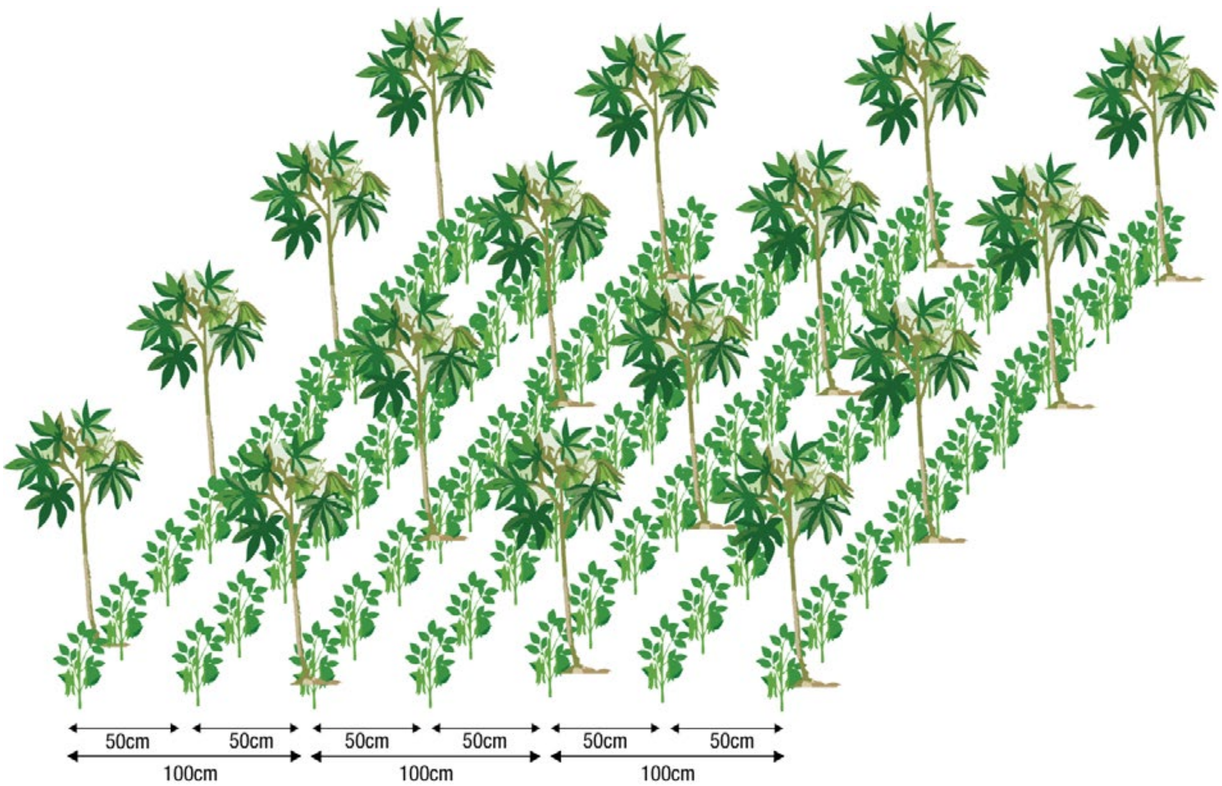


Figure 7.1 Plant association of cassava with beans, planted on flat land.


Picture 7.1 Cassava flat planted with legume intercropping.

Table 7.1 Advantages of cassava intercropping systems.

Advantages
• Increases nitrogen fixation through legume intercropping. • Increases cassava yields in response to greater residual nitrogen from the additional legume plants. • Enhances household nutritional outcomes due to dietary diversity. • Improves groundcover in cassava systems as canopy development is slow. • Supports erosion control due to increased groundcover when cassava is planted on slopes. • Reduces labour for land preparation if annual ridges are not prepared and cassava is planted on a flat surface.

Table 7.2 Things to worry about when practicing cassava intercropping.

Disadvantages
• Competition of some legumes (e.g. cowpea) with cassava • Legume intercropping is only possible in year 1 – in year 2, the canopy is too dense for any legume to proliferate. • Legume harvesting (e.g. groundnuts) may disturb the soil which could affect the cassava roots. • Increased weed pressure on flat planted cassava if no herbicides are used. • Cassava flat planting is new to farming communities in the region and may require a lot of awareness building and initial knowledge sharing.

Permanent raised beds

Permanent raised beds are Conservation Agriculture systems characterized by wide ridges that can accommodate at least two maize rows on the bed and function in the same way as conventional ridges (**Schematic 7**). However, they are not destroyed annually but maintained permanently. The system also allows for surface residue mulch to be applied on the bed as in normal flat-planted Conservation Agriculture systems. The raised beds are designed to be oriented at a slope or gradient of 0.4 to 1% across the slope to ensure that excess water drains out during excessive rains or when fields start to waterlog (**Schematic 6**).

Graded permanent raised beds should be prepared with a height of about 20 cm and a width of 180 cm. Build the bed by moving soil from the furrows to the bed and prepare a smooth flat surface. The remaining beds should run parallel to the first but must all maintain a spacing of 180 cm from furrow to furrow. Prepare twin rows on each bed about 80 cm apart leaving 50 cm from the edge of the bed. Apply residues as mulch cover on top of the bed at 2 to 3 t/ha. Plant maize in 80 cm rows with 25 cm in-row spacing on top of the permanent raised bed. Legumes can be planted on the sides of the bed to increase the groundcover and output of crops per land area. Beds should be 15-20 cm deep. In the following season, the beds will require rebuilding or maintenance. The bed can be rebuilt by taking soil from the furrows to the top of the beds once again to control winter weeds.

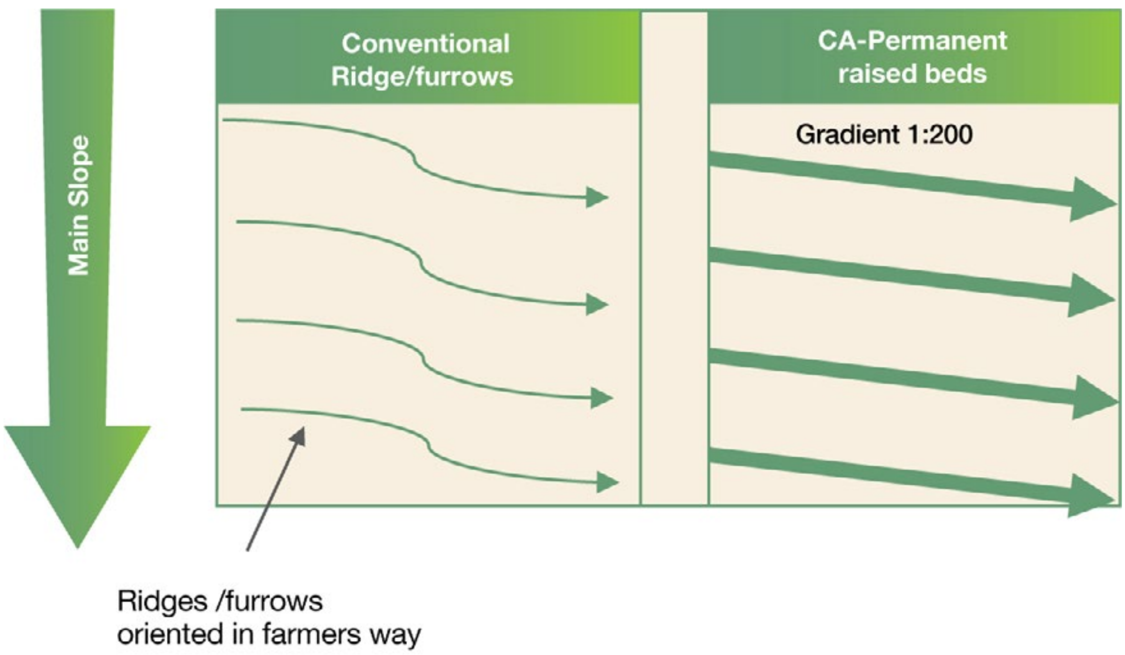


Figure 8.1 Conventional farmer ridge and furrow system (left) and CA permanent raised beds with a gradient of 1:200 (right).

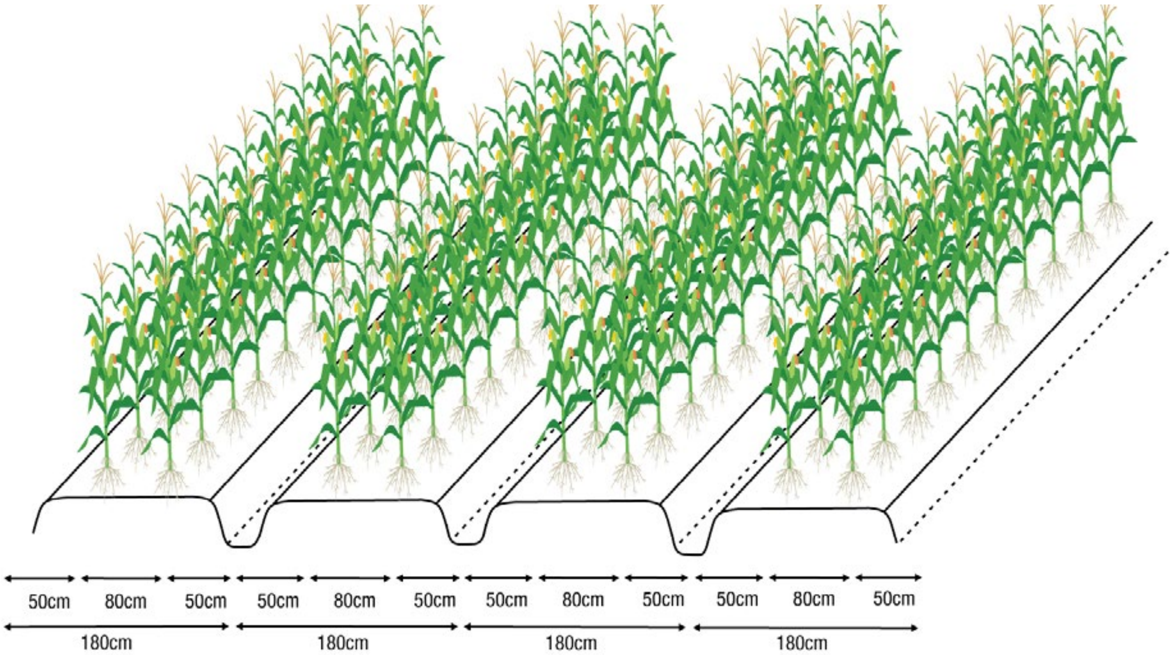


Figure 8.2 Layout and planting distances in a permanent raised bed system. A double row of maize is planted on top of the ridges. The sides of the ridge can be further intercropped with legumes.

Picture 8.1 Permanent raised beds containing maize and soybean.

Table 8.1 Advantages of permanent raised bed systems.

Advantages
• Permanent beds allow for improved drainage in times of waterlogging or excess rainfall.
• Provide greater moisture conservation when the weather is too dry compared with conventional ridges.
• Wider beds reduce direct soil evaporation water losses compared with conventional ridges and furrows.
• The semi-permanent nature of raised beds helps minimize labour associated with land preparation as the beds are not rebuilt but only reformed annually.
• Mulch can be applied on the bed as in other Conservation Agriculture systems.
• Permanent beds allow for intercropping along their sides which increase the output per unit area.

Table 8.2 Challenges associated with permanent raised bed systems.

Challenges
• Permanent beds require skill in bed pegging for the disposal of excess water when excess rainfall is received. • Weed control can be more challenging due to non-flat terrain. • Permanent beds can limit the diversity of crops that can be planted on the beds as well as the planting density as the predefined shape is restrictive and may reduce plant population of crops that need dense planting. • The initial creation of permanent beds require considerable farm labour and may pose the biggest challenge to this system.

9

Choosing cereal and legume varieties

To achieve the greatest yields in each agro-ecological farming system, it is important to choose the right crop varieties suitable to the location. While maize seed is more easily available due to its well-developed formal seed market, sourcing non-commercial cereal and legume seeds can be challenging as most farmers must rely on informal seed sources. In this context, it is important to select varieties and secure their access well before the onset of the cropping season.

9.1 Maize variety choice

To select the most suitable maize variety, farmers must consider a number of important factors, including (a) time to maturity, (b) ability to tolerate moisture and heat stress, (c) resistance to pests and diseases, (d) grain milling quality, and (e) yield potential.

Long duration or late maturing maize varieties tend to have higher yields but require more rainfall. Early maturing varieties, on the other hand, grow faster and mature early thereby performing better in the short seasons. The ability to tolerate moisture or heat stress is important particularly in arid or semi-arid conditions where temperature are high and severe moisture stress on crops is common. Drought-tolerant maize varieties are bred to cope with these adversities and often yield much higher than normal varieties under moisture stress. Similarly, pests and disease resistant varieties are more suitable in environments where pests and disease problems are prevalent. Recently released maize varieties are bred to resist diseases such as grey leaf spot, maize streak virus and cob rot, amongst others. The characteristics of a selection of maize varieties are described below.

a) Open Pollinated Varieties (OPVs)

OPVs self-pollinate, resulting in seeds that are genetically identical to their parents. Traditional maize varieties and land races belong to this category and yields tend to be modest or low. When several OPV genotypes are grown together and pollinate each other, the result is an improved OPV. OPVs are particularly advantageous as they allow farmers to grow the same seed over several cropping season (typically 4-5 seasons). OPVs possess marginal yield decline; greater genetic diversity within each seed resulting in increased resistance, taste preference; easy storage and seasonal tolerance to erratic rainfall. Greater diversity also means less uniformity which make the crops mature at different times. Farmers must source fresh seed after 4-5 years of growing an OPV.

b) Hybrids

A hybrid variety is the results of crossing two different maize in-bred lines with desirable characteristics. Maize has undergone significant improvements over the years in the development of hybrid seeds, which tend to have higher yields than OPVs. Advantages of hybrids include, greater uniformity, more vigorous growth, higher yields and less time dedicated to breeding. However, hybrid seeds cannot be recycled, forcing farmers to buy seeds annually. Hybrids are more expensive and demand high mineral fertilizer for improved yields.

c) Drought tolerant maize

In recent years, CIMMYT and its partners invested heavily in developing drought-tolerant white and orange-coloured maize varieties. Key characteristics of these drought tolerant varieties are as follows:

- Yields are relatively better in dry years. They produce 20-30% more under moderate drought conditions than other non-drought tolerant commercial varieties.
- Greater yield stability which means they produce higher yields in good and bad rainfall seasons.
- Higher yield potential as they contain the best germplasm available in the region (no yield losses in optimal years).
- Resistance to major diseases (e.g., maize streak virus (MSV), Turcicum leaf blight (TLB), and grey leaf spot (GLS).
- Superior milling and cooking quality.
- Very uniform when planted in the field.
- Seed must be purchased every season.

d) ProVitamin A Maize

These are orange-coloured maize varieties that have been biofortified with Provitamin A. These varieties are quite different in colour but often confused with yellow maize which is usually grown as stockfeed. Orange maize is quite different, much sweeter in taste and appreciated by farmers if they have overcome the initial perception that locally consumed maize porridge must be white. Orange maize varieties are available in the form of hybrids or OPVs and possess the following characteristics:

- Orange maize varieties have enriched levels of about 6-8g/g provitamin A (carotenoids), (low levels of Vitamin A in the body can result in morbidity or blindness in humans).
- Provitamin A hybrids are high yielding, drought tolerant and often disease resistant.
- They possess a high micronutrient density and are sometimes referred to as nutrient dense maize varieties.

e) Quality Protein Maize varieties

These can be white in colour but are open pollinated. High in protein content,. the nutritive value in milk protein is 90%, while the average maize variety has only about 40% in protein value.

9.2 Sorghum and millet varieties

Sorghum and millet varieties are traditional cereals grown in southern Africa due to their greater drought resilience, faster maturity, and better adaptation to the environments. However, common to all these cereals is also the lower yield and premature harvesting by birds. Over the past twenty to thirty years, the greater part of southern African countries have seen improved sorghum and millet varieties come on to their markets. Traditional varieties tend to be tall and low yielding while improved varieties are much shorter and higher yielding. However, traditional varieties are usually less vulnerable to bird attacks and their grains less susceptible to weevils. It is not advisable to continuously plant a sorghum crop due to pest build-up. Recommended spacings for sorghum are summarized in Table 9.1 below. The suggested planting time in Zambia falls from the end of November through to the end of December. Fields should normally be kept weed free through manual hoe weeding or the use of herbicides, where appropriate. Harvesting should be done early to avoid bird damage and farmers should utilize bird scares when growing susceptible varieties..

9.3 Choosing legume varieties

The availability of legume seeds poses a major challenge for many smallholder farmers in Eastern and Southern Africa, as the possibility of seed reusability each year by farmers disincentives seed companies to bring the seeds to market. Most legumes discussed here can be grown as intercrops or sole crops. **Table 9.2** highlights recommended planting densities and seed requirements per ha when grown as intercrops or in rotation with cereals.

Table 9.1 Recommended seed rates for sorghum.

Rainfall	<500 mm	500-650 mm	650-800mm	Irrigated
Population (plants/ha)	60 000	90 000	110 000	250 000
Seed required (kg/ha)	5 kg/ha	8 kg/ha	12 kg/ha	15 kg/ha
Row width 90 cm	15.5 cm	8.5 cm	6 cm	3 cm
Row width 75 cm	14.0 cm	10.0 cm	7.5 cm	4 cm

Source: Seed Co Sorghum Grower's Guide

1. Cowpea

Improved cowpea varieties have been available on the market over the past twenty to thirty years. These varieties are erect, determinate, early maturing and have high yielding characteristics. These grains cook easily and are often considered tastier compared with some traditional runner type cowpeas. However, they are highly susceptible to pests such as aphids and hence require periodic insecticide spraying, particularly during prolonged dry spells.

2. Common beans

Common beans have been grown extensively as intercrops by smallholder farmers in Zambia, especially in cooler climates with adequate rainfall. The choice of varieties depends on the agro-ecology or expected rainfall regime of the area. Most beans drop their flowers if they experience excessive rains during the flowering period. Farmers prefer to delay the planting of beans in intercrops until the season starts tailing off to ensure that beans grow on residual soil moisture. Another common challenge is the bean stem maggot. To control this pest, it is advisable to seed dress the beans' seed. In recent years, bean breeding efforts have focused on improving yields under stress conditions and based on farmer taste preferences. More recent efforts have focused on biofortified high iron and zinc bean varieties.

3. Soybean

Soybean has traditionally been grown as a commercial crop primarily for food and feed industries across most countries. Traits to consider when selecting a soybean variety include: (a) maturity, (b) yield potential, (c) disease and pest resistance, (d) iron deficiency tolerance (chlorosis), (e) lodging score, (f) height, and (g) specific soybean quality traits, such as protein and oil content. Due to its commercial orientation, soybean seeds are widely marketed by many seed companies in the Southern African region. In most countries, local seed companies distribute locally recommended varieties. In the smallholder sector, promiscuous soybean varieties that nodulate with indigenous Bradyrhizobium strains without need for inoculation are widely promoted.

4. Pigeon pea

Early or medium maturing varieties are often preferred by farmers due to their fast-maturing characteristics. Though longer season varieties are available, their growing often causes conflict with livestock holders, as roaming cattle and goats will feed on pigeon pea if they do not mature by June/July.

Table 9.2 Recommended planting densities and timing for various legumes.

Crop	Sole crop in rotation in maize				Intercrops with maize				Recommended time of planting
	Plant density/ ha	Seed requirements kg/ha	Attainable yield (kg/ha)	Days to maturity	Plant density/ha	Seed requirements kg/ha	Attainable yield (kg/ha)	Days to maturity	
Cowpea	2-300 000	20-40	2500	70-90	1-150 000	10-20	800-1000	70-90	Same time as cereal
Common beans	+/-200 000	60-100	6000	95-110	+/-100 000	45-50	1000 (???)	95-110	Same time as cereal
Groundnut	74 000	80	4000-6 000	100-180	37 000		1500	100-180	Same time as cereal
Soyabean	444 000	90	5000	100-140	222000	45	1500	100-140	Same time as cereal
Pigeon pea	22000	50	2500-3000	151-200	11 000	25	2000	151-200	Same time as maize
Mucuna	44000	40	4000		22 000	20	1500		2-3 weeks after maize
Dolichos lab-lab	44000	20	3500		22000	10	1000		1-2 weeks after maize
Jack bean	44000	40	4000-5000		22000	20	1500		Same time as maize

10

Land preparation

Land preparation often requires the most amount of time and labour cost, particularly if carried out manually. Weeds that germinate and grow before planting are often the biggest reason why farmers decide to plough or till their fields prior to planting. Traditionally, land preparation has involved tilling, a process where soil is turned over to ensure that the seedbed is free of weeds and hence suitable for planting crops. Conventional tillage using hoes or ox-drawn/tractor drawn ploughs often results in excessive soil erosion and a loss of water due to run-off. However, one advantage of tillage is the incorporation of organic materials usually left on the surface, which then accelerates their decomposition and results in the fast release of soil nutrients such as nitrogen, potash and phosphorus to crops. Despite these benefits, soils loosened using conventional tillage often become compacted quickly, resulting in higher soil degradation in the longer term.

10.1 Conventional tillage

Although commonly practiced by many farmers in Zambia, the following important measures can help reduce soil degradation:

1. Ploughing or tillage should run across the main slope to reduce the loss of both soil and water.
2. On sloppy ground, farmers should install mechanical barriers commonly known as channel terraces, contour ridges or use grass or hedge strips at intervals of 20 to 40 m depending on slope. The main objectives behind the use of mechanical channel terraces are to reduce the slope length and minimize soil erosion, and to intercept the runoff and divert it to a safe point. Common structures used in the region include level channel terraces or contour ridges, *Fanya Juus* and *Vetiver or other grass strips.*

However, to be sustainable, conventional tillage should be used in conjunction with

biological erosion control methods as well as intercropping with effective cover crops such as cowpea and pumpkins. Crop rotations and fallowing could also be used to enhance soil fertility.

Conventional tillage is best used on relatively flat land where erosion risks are minimal, and on fields where weeds are a serious problem. It may also be used to incorporate manure and crop residues and where fertility management is possible, through the application of organic and inorganic fertilizers.

Table 10.1 Advantages with conventional tillage.

Advantages
• Provides a clean seedbed.
• Results in greater soil nutrient mineralization.
• Distributes soil nutrients throughout the soil.
• Enables effective weed control at planting.
• Exposes pests to predators and unfavourable conditions.
• Aerates the soil.

10.2 Conservation Agriculture

Conservation Agriculture (CA) began in the 1970s in Zimbabwe and South Africa and spread to Zambia, Malawi and elsewhere. CA is premised on three key principles: (1) minimum soil disturbance, (2) the provision of permanent soil cover, and (3) the use

Table 10.2 Challenges associated with conventional tillage.

Challenges
• Leaves a surface susceptible to splash and sheet erosion.
• Results in high nutrient leaching.
• Smooth surface susceptible to crusting.
• Results in a decline in soil organic matter content and increases erosion.
• Results in limited rooting volume due to a high resistance layer (plough pan) formed at shallow depths.
• Requires high draft power.
• High moisture loss.
• Disrupts the lifecycle of beneficial soil organisms.
• Requires greater labour costs for soil preparation.

of rotations or associations (**Figure 10.1**). These CA principles are applicable to a wide range of crop production systems from low-yielding, rainfed conditions to high-yielding, irrigated conditions. However, the techniques used may vary from place-to-place depending on farm power, system management conditions and farmer circumstances. CA aims at rebuilding the soil, optimizing crop production inputs, especially labour, as well as increasing profits. The social and economic benefits gained from combining production and protecting the environment under CA, including reduced

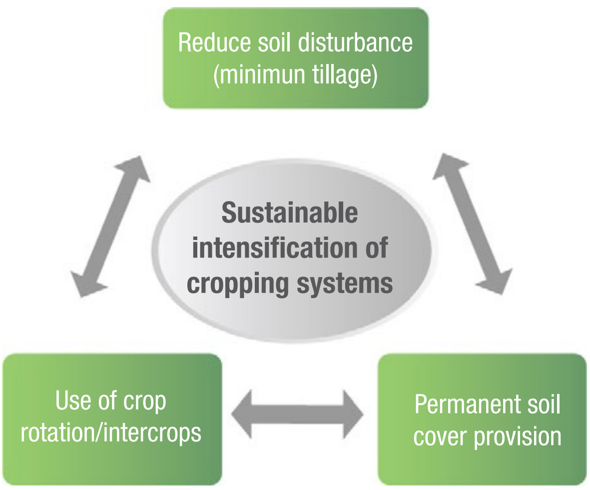


Figure 10.1 The three principles of Conservation Agriculture.

input and labour costs, are greater than those from production alone. With CA, farming communities become the providers of healthier living environments for the wider community through reduced use of fossil fuels and through conservation of environmental integrity and services.

Other complementary practices also often known as good agronomic practices (GAPs) govern the implementation of CA. They comprise: (i) the timely implementation of preparation, planting, manuring and fertilization, as well as the control of weeds and pests, (ii) precise operations, with specific attention to detail and undertaking tasks carefully and completely, and (iii) the efficient use of inputs where labour, time, seeds, stover, manure, fertilizer and water resources are not wasted.

11

Timely planting and planting depth

11.1 Timely planting and use of climate information

In rainfed systems, farmers often fail to plant crops on time. Due to the changing climatic and seasonal weather patterns, farmers need to ensure that they make full use of any available moisture in the soil by timely planting at the onset of the cropping season. Late planting often results in lower yields for cereals and legumes. The following key steps will ensure farmers optimize yields in any rainfall season:

a) **Climate services information:** In many countries, meteorological services organizations often give seasonal forecasts for expected rainy seasons. It is important that farmers make use of this information that is reported via television, radio, newspaper as well as social media platforms such as WhatsApp. To access this information, farmers are advised to ask their local extension advisers on where to find this information in their area.

b) **Timely planning:** It is important that farmers know well-before the season starts what crops they intend to grow and on which fields. Once a decision is made, the farmer must then calculate the required inputs (seeds, fertilizer and agro-chemicals) for the different plots of land. Local extension officers are available to help further if needed.

c) **Timely land preparation:** Irrespective of weather, it is always important to prepare the land in a timely manner before the season starts. Attempting to prepare land when the season has started often leads to disastrous results as land preparation demands a considerable amount of energy, time and resource.

(d) **Weed control:** Farmers must ensure all planting fields are free of weeds.

11.2 Planting depths and when to plant in rainfed systems

When planting by hand it is important to ensure the following:

(a) The seed (legume or cereal) is planted at a depth of between 4 and 6 cm.

(b) The seed must be covered with soil and soil must be pressed firmly by foot or hand to ensure the soil has good contact with the seed.

)c) In rainfed systems, planting should only be carried out when the soil is wet at least within the top 20 cm of soil depth. To achieve this, at least 30-50 mm of rainfall is required in 1-3 consecutive days. After this amount of rainfall is received, planting must be carried out within three days of this required rainfall amount. If not, the soil may become too dry for germination to take place successfully. Heavier clay soils generally require more rain to get fully wet compared to sandy or light textured soils.

(d) Soaking the seed by immersing it in water overnight is a possibility to improve germination after planting, but only soak enough seed to be planted the following morning. The seed may rot or get damaged if soaked for longer than a day.

12

Weed control strategies

A weed is any plant that grows where it is not wanted and competes with cultivated main crops for nutrients, moisture and light. Weeds are mostly undesirable in any cropping system as they cause yield reduction through competition for the same resources needed by the crop and often interfere with crop harvesting. Weeds also provide a shelter for pests and diseases that can attack the cultivated crop, leading to a reduction in crop yields and quality of grain. The yield reduction from weeds can be a serious problem in smallholder farming systems (**Picture 12.1**).

Studies conducted in Malawi in 2018 showed that returns to one weeding operation is equivalent to 1000 kg/ha of maize grain yield in systems that farmers weeded up to three times per season. Each weeding enabled a farmer to harvest one extra tonne of maize. Elsewhere, studies have suggested that the benefit of one weeding can be equivalent to one bag of top-dressing fertilizer.

12.1 When to control weeds

In maize, the most serious yield reduction due to weeds happens within the first six weeks of crop establishment. However, effective weed control starts from the time of land preparation until harvest. Farmers should strive to prevent weeds from growing to the point of seeding as this helps to reduce the seed bank in subsequent seasons. Some weed seeds are thought to remain dormant for up to 20 years. To control weeds effectively, the farmer needs to continue reducing seed numbers dormant in the seed bank. Weeds are also the biggest challenge in the initial years of practicing CA. It can take about 3-5 years for the number of weeds in the soil to be reduced for fewer weeds to grow. While CA improves soil fertility, this improvement also encourages weeds to grow. Weeds with stoloniferous growth habit such as couch grass and yellow nutsedge are the most difficult weeds to control because they are difficult to uproot.

Weeds are best controlled during the following times:

(a) Soon after harvesting to prevent seed multiplication during the dry or off crop season.

(b) Following the rains but before harvest to manage winter weeds, minimize moisture loss and make harvesting easier.

(c) During the cropping season, before or at planting.

(d) Before they set seed.

Picture 12.1 Maize crops heavily infested with weeds.

12.2 How to control weeds

Intercrops increase the plant density in the free space between planting rows and have a shading effect on emerging weeds. Fewer weeds emerge in intercropped systems compared with sole cropping. Weed pressure is also generally higher under the following conditions.

a. High soil moisture conditions: This may arise from excessive rains or residual moisture as the season tails off. The use of crop residues under CA helps to increase moisture and may result in more weeds although residues are known to smother weeds.

b. High fertility conditions. Fertile soils create conducive conditions for weed growth. It is important to ensure that improved soils are not taken up by weeds through effective weed control methods.

Apart from mechanical methods of weed control, chemical weed control methods using herbicides (**Table 12.1**) are available in most countries. Farmers should be careful when using them as they can kill the crop or may poison the user if recommendations and safety measures are not properly followed. It is important for farmers to carefully read the labels on any chemical herbicides. Some herbicides such as glyphosate can kill everything that is green (non-selective desiccant), while others (selective) may kill broad leaved plants or grasses only (**Tables 12.1 and 12.2**).

The most widely used herbicide applied before planting is glyphosate. Glyphosate needs at least four hours free of rain after application and may be applied at the rate of 3 litres per ha in a knapsack sprayer. Further details on herbicides should be sought from local extension staff for farmers planning to use herbicides to help reduce labour pressure for weed control.

Table 12.1 Some recommended application rates for herbicides used in cereal crops.

Herbicide	Recommended rate (l/ha)	Weed species controlled	Notes
Round Up (Glyphosate)	• Sandy soil: 1.5-2.5 • Clay soil: 2.5-5.0	Couch grass, Wandering jew, *Ricardia scabra*, Striga, Sedges, Rapoko grass	Application rate will depend on weed species and height
Atrazine (Aat rex)	• Sandy soil: 3.6 • Clay soil: 4.5-5.5	Wandering jew, Mexican clover, Sedges, Witch weed, Black jack, some grasses	Use higher rates when weeds have emerged. Minimize runoff in fields treated with Atrazine
Dual (Metolachlor)	• Sandy soil: 1.0 • Clay soil: 1.0-1.2	Couch grass, Rapoko grass, Shamva grass, Sedges, some broadleaves	Use higher rates for control of sedges
Basagran (Bentazon)	• Sandy soil:3.0 • Clay soil:3.0-5.0	Wandering jew, Mexican clover, Sedges, Witch weed	Application rate will depend on weed plant height
Accent (Nicosulfuron)	• Sand and clay soil: 46 grams/ha + a wetter, apply in 200-300 L water/ha	Shamva grass, Rapoko grass, Couch grass	Ensure good agitation of the mixture during application
Harness (Acetochlor)	• Sandy soil: 0.5-1.0 • Clay soil: 1.0	Rapoko grass, Shamva grass, Couch grass, some broadleaves	Normally used with broadleaf herbicide. Apply higher rates when used alone
Bullet (Alachlor)	• Sandy soil: 2.5-3.5 • Clay soil: 3.0-4.0	Rapoko grass, Shamva grass, Couch grass, some broadleaves	Apply immediately after planting

Table 12.2: Some recommended application rates for herbicides used in legumes and other crops.

Herbicide	Recommended rate (l/ha)	Weed species controlled	Notes
Round Up (Glyphosate)	• Sandy soil: 1.5-2.5 • Clay soil: 2.5-5.0	Couch grass, Wandering jew, *Ricardia scabra*, *Striga*, Sedges, Rapoko grass	Application rate will depend on weed species and height
Dual (Metolachlor)	• Sandy soil: 1.0 • Clay soil: 1.0-1.2	Couch grass, Rapoko grass, Shamva grass, Sedges, some broadleaves	Use higher rates for control of sedges
Basagran (Bentazon)	• Sandy soil:3.0 • Clay soil:3.0-5.0	Wandering jew, Mexican clover, Sedges, Witch weed	Application rate will depend on weed plant height
Agil (Propaquizafop)	• Sandy soil: 0.5-1.5 • Clay soil: 2.0-3.0	Rapoko grass, Shamva grass, Couch grass	Ensure thorough agitation during mixing and spraying

13

Soil Fertility Management

The continuous production of sole crops, a practice called monoculture, usually results in the decline of soil fertility over time. The use of cereal-legume rotations or intercropping are effective methods for improving soil fertility in cropping systems.

In general, legumes have the capacity to acquire nitrogen through biological nitrogen fixation processes. Cowpea, groundnut and pigeon pea, can fix high amounts of nitrogen into the soil (> 30-100 kg N/ha). In general, the higher the amount of biomass produced by a legume, the higher the amount of nitrogen that is fixed. However, some legumes such as soybean can only fix nitrogen if the seed is inoculated or coated with a rhizobia inoculant which helps the crop capture naturally occurring atmospheric nitrogen into the soil. The nitrogen is fixed by the plant in root nodules. When the crop dies, some of the nitrogen left in the soil can be taken up by the next crop, mostly benefitting crops that are planted after the legumes. The use of legumes either as sole crops in rotation with maize or as intercrops, increases maize yields as other nutrients, apart from nitrogen, are activated to become available to the next crop.

The most important nutrients required by crops in large quantities on an annual basis are Nitrogen (N), Phosphorus (P) and Potassium (K). Continuous cropping results in a decline in these primary nutrients and eventually will require replenishment through organic or inorganic fertilizers. Nutrients that are required in smaller quantities such as Sulphur, Calcium, Zinc, Iron, Molybdenum and others are often found in specialized fertilizers and can also be found in sufficient quantities in organic manures.

13.1 Use of Manure

Apart from nitrogen fixation from legumes, nutrients required by crops can also be added to the soil using organic manure from cattle, goats, chicken and pigs. Organic manure may also be prepared from compost. Local extension officers can advise farmers on how to prepare manure from commonly decomposing organic materials. Farmyard manures save farmers from purchasing expensive mineral fertilizers and help improve the soil's ability to hold water. Rates of application vary depending on the quality of compost or manure, but in general 5 to 10 tonnes/ha are needed. Application rates may be lowered if farmers apply manure in rows or planting stations instead of broadcasting it.

13.2 Basal Fertilizer

Basal fertilizer is applied to crops in the planting phase and distributes slow-release nutrients that are gradually introduced to the crop in the early stages of growth and during its lifecycle (**see Table 13.1**). The main nutrient needed by maize in its early stages of growth is phosphorus (P). Due to its limited mobility, it must be applied at planting. Most basal fertilizers, known in several countries as NPK, contain enough nitrogen to meet the needs of maize and other crops in their early stages. About one third of the recommended fertilizer nitrogen (N) rate can also be applied at planting. The crops' remaining nitrogen needs may be supplemented through urea top dressing, ammonium nitrate or other nitrogen-rich fertilizers.

Farmers should seek the guidance of local extension staff on recommended fertilization strategies for their area and soils (**Table 13.2**). Most soils become acidic over time and periodic application of lime every 3 to 5 years is recommended. Lime helps to increase the pH and to reduce acidity in the soil.

13.3 Topdressing Fertilizer

Top dressing fertilizers such as urea or ammonium nitrate can be applied to maize and other cereals from 4 to 6 weeks after emergence to supplement crops with extra nitrogen (**Table 13.2**). A common deficiency symptom of nitrogen is the yellowing of the crop. A dark green coloured maize crop indicates adequate nitrogen fertilization. Top dressing fertilizer is applied as side dressing in small quantities. In high rainfall areas or on sandy soils, top dressing fertilizer may need to be applied twice as rainfall may wash nitrogen out of the soil. Farmers should avoid applying top dressing fertilizer when the soil is dry as this may burn the crop. Always ensure top dressing is applied only after having received at least 20 mm of rainfall.

Table 13.1 Fertility management techniques.

Fertility amendment	Recommended practice	Importance
Use of manure/composts	• Organic matter management practices i.e., Composting, Green manure, Farmyard manure. • Maintain high quality of manure.	• Build soil organic matter and improve soil. structure and fertility.
Mineral fertilizers	• Use phosphorus and nitrogen fertilizers e.g., TSP, DAP, NPK, SSP. • Apply fertilisers containing micro-nutrients and lime to improve soil responsiveness. • Apply correct methods and quantities. • Check fertility or health of soil to guide actions.	• Improve soil fertility rapidly and improve crop production. • Address high nitrogen and phosphorus deficiencies. • Increase biomass production for soil cover. • Build soil organic matter and improve soil structure and fertility.
Lime	• Use agricultural lime or dolomitic lime for soils deficient in magnesium. • Rates may vary from about 200-1500 kg/ha. • Apply fertilizers containing lime such as calcium ammonium nitrate.	• Reduce acidity or improve pH to between 5.5 and 6.5. • Nutrient uptake improves when soil is neutral or slightly acidic. • Most mineral fertilizers make soil acidic, so the use of lime helps to mitigate that effect.

Table 13.2 General recommended fertilizer rates for maize where no specific soil analysis or local recommendations are available.

Target yield (t/ha)	Nutrient requirements (kg/ha)		Basal fertilizer (kg/ha)	Top dressing
	Nitrogen	Phosphorus	DAP (kg/ha)	UREA (kg/ha)
2	30	10	60	40
3	60	20	120	80
4	90	30	180	120
5	100	40	240	160

14

Pest and Disease Control

Pest control is an important component of good crop management. Therefore, crops need close and frequent observations (scouting in the field) to detect any pests and disease infestations and correct them before they can cause any permanent damage to crops. For maize, the most common pest is the maize stalk borer and more recently, the Fall Armyworm (FAW). For legumes such as cowpea, aphids are a common problem. Stalk borer control is achieved through the application of granular pesticides on the funnels of growing maize plants at the 4 to 6-week leaf stage. Insecticides can be applied once pests reach commercial threshold levels.

FAW is a relatively newer pest that causes serious damage to maize and consequent yield losses of up to 30%. For the control of FAW (**Figure 14.1**), some low-cost solutions such sand, ash and laundry powders has been reported as effective. Further recommended cultural methods for FAW control include the use of intercrops and rotations with legumes and early planting.

Figure 14.1 FAW damage to maize.

Harvesting and Post-harvest Management

For most smallholder farmers, harvesting crops is a considerably labour-intensive endeavour which often requires some 20-30% of the total labour needed to produce a given crop. Yield losses from the late harvesting of crops may occur hence farmers must ensure that crops are harvested on time. Common challenges arising from late harvesting include:

- Weevils and other pest attacks on crops.
- Crop rotting in the field prior to harvesting.
- Feeding on crops and their residues by roaming livestock if crops are not removed from the field.

Harvested crops may also become spoiled due late rains and crop heaping which result in excessive moisture and rotten crops. Harvested crops should be allowed to dry sufficiently before threshing or shelling and be stored in a dry area to avoid rotting.

Various drying options are available which range from sun drying, solar drying and more advanced techniques employing electric drying systems. Maize drying may be easily achieved by cutting and placing standing stalks on stacks which allow for a slow drying out without direct sun exposure. Alternatively, cobs may be removed from the stalks when mature and dried in a raised crib with a roof for shedding to prevent direct sun heating and then threshed on a clean surface. The grain can be further cleaned by winnowing to remove any chaff or unwanted objects. For maize grain to store well, the moisture content must be below 12.5%. Similarly for legumes, mature dry pods can be harvested and dried in the sun before threshing on a clean surface. Harvested grains are dried further, cleaned by winnowing and stored in suitable conditions. For proper storage of legume grain, the grain must be dried in an environment with a below 11% moisture content to avoid spoilage.

To verify whether the grain is dry enough to be stored, a simple technique can be applied. A few dry grains are inserted into a dry glass bottle together with 2-3 spoons of salt. The contents can be mixed thoroughly for a few minutes and left for 15-20 minutes. If the salt particles are left sticking on the glass walls, the salt has absorbed some moisture from the grains. This indicates that the grains are not yet dry and further drying is required. If the salt particles do not stick to the glass walls, the grain is dry enough for storage.

As soon as threshing/shelling has been completed, the next step is to store the grain in a place where losses due to weevil attacks are minimized. Different types of storage methods are used from country to country and across cultures. Post-harvest losses of grain through weevil damage and other pests or diseases can amount to 20-30% in maize negatively impacting food security and farmer incomes. What follows is a brief description of the various grain storage methods that are applied by farmers in the Eastern and Southern Africa region.

Grain storage structure: Raised or suspended grain storage structures with compartments are used for storing different types of grain. Inside walls are plastered with a mixture of cow dung and clay. This permits aeration and the exchange of gases with the outside environment and helps to keep the grain cool.

Metal Grain Silos: A metal silo is a cylindrical structure, constructed from a galvanized iron sheet and hermetically sealed (airtight). Metal silo technology has proven to be effective in protecting harvested grains from attacks by storage insects and rodent pests. Any pest within the silo dies of suffocation as no oxygen can enter the silo. Silos can come in various sizes, and can store anywhere from 100-3000 kg of grain. Metal silos cost between USD 30 to USD 100 per silo.

Hermetic storage bags: The hermetic storage bags system originates from Purdue University in the United States. The bags are also commonly known as Purdue Improved Cowpea Storage (PICS) as they were originally designed for storing cowpea in Chad. With the PICS system, farmers place their grain maize or cowpea in a polyethylene bag and seal it by tying it with a string. This inner bag is inserted into another identical polythene bag and sealed with a string, and the double-bagged grain is then inserted into a third nylon bag. The principle is similar to that of metal grain silos as both systems ensure that air is kept out thereby suffocating the insects or pests. All materials required for this system are affordable to farmers, and PICS are increasingly available in cowpea-growing regions.

Farmers can treat grains with recommended storage chemicals to control damage, especially when storing in containers that are not airtight. Grain protectants are commonly available in Zambia ad well as affordable, however, as with all chemicals, farmers need to read the label carefully and follow the instructions during use.

The hermetic storage bags system.

Input and output marketing

Seed quality and access

- Good harvests begin with good seed selection.
- Quality seeds are essential for the growth of strong and healthy crops which can resist diseases or even drought.
- Good quality seeds can be purchased from trusted sources such as certified seeds stockists or agro-dealer shops.
- Farmers can produce their own seeds however seed selection and management are very important as high-quality seeds offer higher yields.
- Farmers should ensure that seeds are handled and stored properly. Poor storage of seed results in poor germination and vigour.

Key factors to consider when purchasing quality maize and legume seed

- **Adaptability**

  Selected maize and legume seed should be adaptable to the existing soil and climate conditions. It is important that the seed of choice is suitable for your area before purchasing.
- **Yield Potential**

All things being equal, choose seeds with high yield. This will determine the profitability of your farm.

- **Cost of Seed**

  Farmers should purchase quality seeds within the limits of their budget. To note, good quality seed is more costly. Indirect costs include seed handling and transportation.
- **Pests and diseases resistance**

  Seeds that are resistant to diseases and pests will help reduce risks and losses. Farmers should purchase quality seed of crop varieties that are resistant to major diseases and pests common in their area. While it is often difficult to find seeds with all the desired traits on the market, choose seeds based on the most important yield limiting factors.

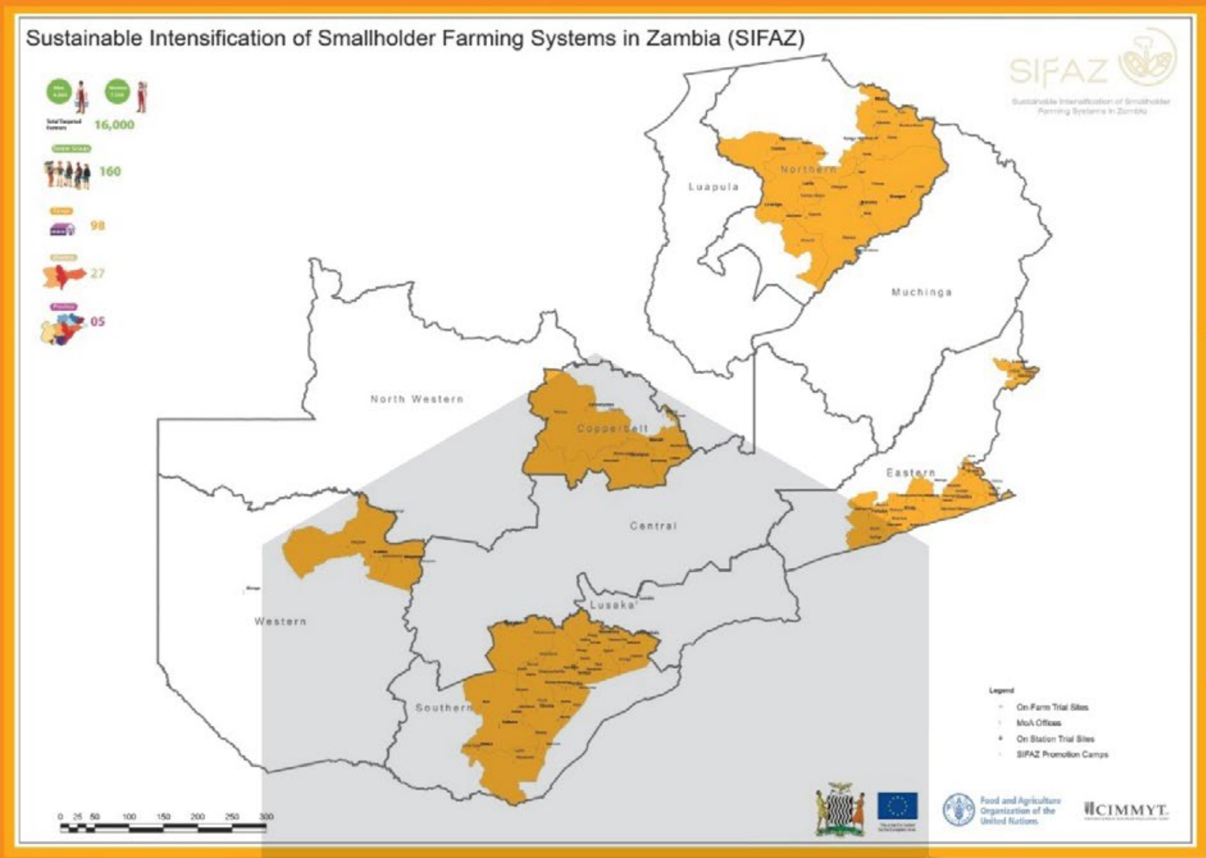
Understanding smallholder participation in maize and legume markets

- Market participation is the ability of smallholder farmers to participate in a market efficiently and effectively.
- Smallholder farmers' market participation in Zambia is limited due to biophysical, socio-economic and institutional factors. Smallholders face high transport and production costs due to geographic barriers such as remoteness and/or biophysical limits to productivity (e.g., water availability) as well as poor road infrastructure. Together, these increased costs reduce competition.
- Smallholder farmers in Zambia have limited productive assets such as land, livestock, labour, and farm equipment which limits their capacity to produce and market any surplus.
- They face difficult and variable institutional arrangements including difficulties in contract enforcement conditions, product grades and standards, access to credit, insurance, and technical information through extension services and ICTs.

- They also lack commercial information, bargaining, screening, monitoring and coordination skills. This uncertainty increases the risks to farmers, which must be managed.
- Due to these constraints, smallholder farmers avoid risks which derive from adverse weather, pests and diseases, unstable prices and policy environments.

Potential solutions for integrating smallholders into the markets

- Support socially inclusive market development through cooperatives, farmer commodity groups, auction markets and enforced forward contracts.
- Facilitate the development and implementation of policies that are supportive of smallholder market integration.
- Technological solutions
  - Facilitate the development and implementation of warehouse receipt systems.
  - Improve access to market information, weather, pest and disease information through use of ICTs.
  - Transfer risk through weather-based index insurance services for seeds and other inputs.
  - Reduce transport costs through the use of e-commerce.
  - Facilitate access to subsidised credit and the reduction of credit risk through collaboration across value chain actors.



Disclaimer: Some of the information presented in this manual is general in nature. Farmers should consult with their local extension agents for specific information regarding growing cereal-legumes on their farm. All persons using the information in this manual assume full responsibility for application of the recommendations made.

This publication was produced with financial support of the European Union (EU). Its contents are the sole responsibility of FAO/CIMMYT and do not necessarily reflect the views of the EU.