Chapter 2
Managing Crop Rotations in No-till Farming Systems

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Abstract Crop rotation is an important pillar of no-till (NT) cropping systems for soil fertility management, and pests and disease control. In this chapter, the potential benefits of crop rotations under NT systems are discussed and challenges highlighted, including possible solutions where it was practical to do so. Cereal-grain legume rotations are the most ideal for small farms, especially the dual-purpose legumes, which play a significant role in nutritional diversity at the farm level. This is because the legume will produce edible leaves and grains – and sometimes mature earlier than the main crop covering critical food deficit periods before the main crop is harvested. However, limited landholdings prevent widespread adoption of cereal-legume rotations. Large scale farmers have many crop rotations options, and they are able to make a profit due to fuel and labor savings with NT in combination with cultivating cash legumes on a large scale, which have multiple uses as food or feed. In the future, the design of crop rotations has to address a range of issues, especially for small scale farmers, including: (a) small land sizes; (b) multiple uses of legumes crops, including leaves; (c) crop-livestock integration and use of crop residues as livestock feed; (d) poorly developed markets for legumes; (e) differences in planting techniques between legumes and non-legumes; and (f) farmers perception of risk. It is concluded that crop rotation is an integral component of good agricultural practice and is much more critical in NT systems where pests and diseases outbreak is high, and additional N from nitrogen fixation needed.

Keywords Crop productivity · Soil fertility · Pests and diseases · Weed control

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2.1 Introduction

Crop rotation is the strategic practice of growing different types of crops in a pre-planned sequence on the same field. Crop rotation along with NT and mulch cover constitute the tripartite principles that define conservation agriculture (CA) or NT systems farming (see FAO CA web site: http://www.fao.org/ag/ca/1a.html). The retention of crop residues and absence of soil inversion in NT systems may proliferate pests and disease outbreaks, thus crop rotations are particularly important for pests and disease control in NT farming systems (Morrison et al. 2017).

Crop rotation options can start from the very simple 1-year rotation cycle including only two crops, such as maize (*Zea mays* L.) followed by soybean (*Glycine max*. (L) Merr.), to more complicated 3-year rotation cycles involving as many as five crops. The choice of rotation cycle and the component crops depend on several agronomic and economic factors including source of moisture (rain or irrigation), soil nutrient status, input markets, crop duration, and crop uses, including consumption or marketing (Jodha and Singh 1990). In Australia for example, the sequence of crops can flexible, long or short phase, not repeated or fixed, and depends of locality (Wolfe and Cregan 2003; Lawes 2015). The long-phase rotation system involves several years of a pasture phase followed by a number of years of cropping. The short-phase rotation comprises alternating years of pasture followed by a crop sequence such as wheat followed by lupin. When the conditions are favourable, the rotation of two or more crops such as maize followed by soybean and then vegetables can be done within 1 year (Wolfe and Cregan 2003; Kirkegaard and Hunt 2010). Another interesting complex rotation comes from Brazil, NT production generally involves four main crops i.e. soybean, maize, wheat, and oats (Brown et al. 2001). Two crops are fitted in 1 year i.e. maize or soybean in summer and wheat or oat in winter (Brown et al. 2001). Some farmers may include other crops in the double-crop system, but this depends on the farmers production decisions and the costs.

Crop rotation can be considered as one of the best strategies for yield improvement, although it requires increased expertise, equipment, and different management practices. Certain insect pests and diseases may spread easily from one crop to the next through the crop residues and careful design and management is needed (Kirkegaard et al. 2014). The objective of this chapter is to discuss the agronomic importance of crop rotations in NT farming systems with a special focus on soil nutrient status, and pest, weed, and disease management. Additionally, crop rotations options suitable for various systems, including those of different scale and in different climatic regions, and the challenges and opportunities for effective rotation cycles are discussed.

2.2 Effect of Crop Rotation on Soil Fertility

Crop rotation influences soil fertility through several aspects and mechanisms including, soil erosion control through increased infiltration, reduced soil compaction, reduced soil crusting, nutrient addition such as N, soil organic matter build up, and increased biological activity (Franzluebbers 2002; Rusinamhodzi et al. 2009, 2011; Castellanos-Navarrete et al. 2012; Fuentes et al. 2012; Nyamadzawo et al. 2012). Yield increases under real farmer conditions are often used as a proxy for improved soil fertility. As can be shown in Fig. 2.1, crop rotation with NT is superior to NT without rotation, especially in the long-term (Rusinamhodzi et al. 2011). Although the magnitude of effects differ in time and place, there is widespread agreement on the positive effects of crop rotations on system productivity, including yield (Rusinamhodzi et al. 2012; Thierfelder et al. 2013). Most studies that have assessed crop rotation in NT systems generally reported positive effects on crop yields, agreeing with Karlen et al. (1991), who reported that rotations are likely to produce higher yields across soil fertility regimes. Higher yield for NT with rotation than with continuous monocropping is attributed to a combined effect of multiple factors that include reduced pest infestations, improved water use efficiency, improved soil quality as shown by increased organic carbon, greater soil aggregation, increased nutrient availability, and greater soil biological activity (Hernanz et al. 2002; Wilhelm and Wortmann 2004; Kureh et al. 2006).

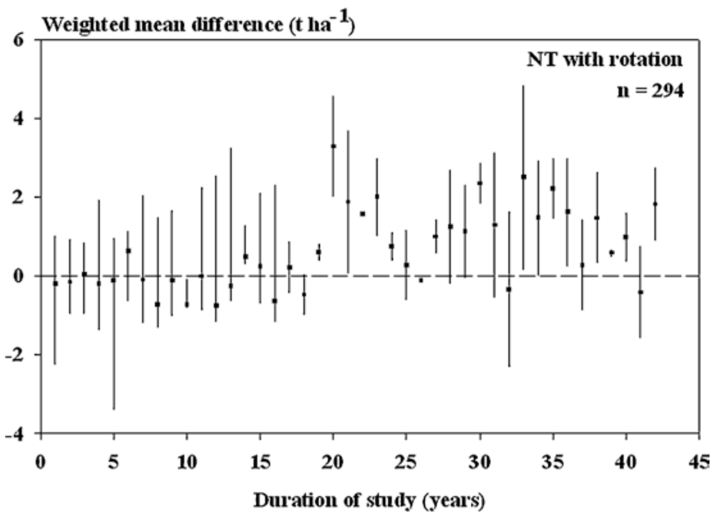

Fig. 2.1 Weighted mean differences in maize grain yield over time between no-tillage with rotation and no-tillage without rotation. Although effect sizes are generally positive, real yield benefits start after 20 years of production. (Adapted from Rusinamhodzi et al. 2011)

2.2.1 Effect of Crop Rotation and Soil N Status

Crop rotations involving legumes improve soil properties and reduce mineral N fertilizer requirements of the following cereal crop if biomass production is large and the harvest index is small (Ojiem et al. 2014; Franke et al. 2018). This is due to the decomposition of N-rich crop residues that the legume crop produces due to biological N fixation (Baijukya et al. 2006). Several factors determine the actual contribution of legume residues to the N nutrition of the next crop, including non-N nutrition provided to the legume, genetic potential, availability of the right strain of rhizobium for effective nodulation and symbiosis, as well as how the legume crop residues are managed at harvest (Giller 2001; Franke et al. 2018). Ideally, the legume residues should be retained in situ to maintain a positive N balance, especially in N-poor environments. In some cases, carefully planned nutrient management in combination with crop rotation can eliminate the need for purchased fertilizer. There is also the potential for non-N benefits in legume-cereal rotations e.g. during the legume phase of the rotation, the crop can utilize the residual soil P and K that were left-over during the non-legume phase of the rotation. There is also improved phosphorus (P) availability following a legume (Pypers et al. 2007). Legumes contribute to P solubilization through acidification of the rhizosphere due to proton release from their roots.

2.2.2 Effect of Crop Rotation on Soil Organic Matter (SOM)

The amount of organic matter in the soil is a common indicator of soil health and productivity (Cardoso et al. 2013). The build-up of SOM is directly related to the types of crops grown, root biomass production and distribution, above-ground biomass production, as well the management of the crop residues at harvest (Magdoff 1993). No-till in combination with high biomass crops, such as green manure legumes, have a very high chance of increasing SOM (Baijukya et al. 2005). No-till systems involving crop rotations are associated with reduced decomposition rates, which is beneficial in maintaining SOM mostly on the soil surface, though this depends on soil type and climatic conditions (Ogle et al. 2019). Powlson et al. (2014) after a meta-analysis observed that farmers who practice NT have a tendency to plough conventionally after a few years, such that the potential SOM benefits of NT are easily lost. For this reason, the actual effect of NT systems on SOM is contested or require a long time to show (Govaerts et al. 2009; Sapkota et al. 2012)

2.2.3 Effect of Crop Rotation on Biological Activity

Soil microorganisms respond positively to the amount of crop residue or soil organic matter content in the soil, especially the upper top soil (Green et al. 2007). Crop rotations that deliberately include more crops are likely to lead to more soil organic matter and biological activity (Magdoff 1993). Soil organisms that are active in the soil, include bacteria, fungi, actinomycetes, protozoa, yeast, algae, earthworms, and insects.

Increased organisms and their diversity in the soil is important for regulating decomposition, nutrient cycling, soil organic matter dynamics, and improvement of soil physical properties. A comprehensive synthesis of NT systems under the rain-fed conditions by Mafongoya et al. (2016) revealed high fauna population (termites, ants, centipedes, and beetle larvae) in NT systems compared with conventional tillage practices. Nhamo (2007) observed that at least 120% more termites and 60% more earthworms were observed under NT than the conventional practice. The abundance of termites and earthworms in NT suggests that NT with retention of crop residues increases biological activity. Ayuke et al. (2019) in a similar long-term trial reported significant increases in soil fauna taxonomic richness and abundance in NT systems compared with conventional tillage practices. The increased abundance of soil fauna under NT systems lead to improved soil physical properties such as infiltration, porosity, aggregate stability and hydrological properties (Briones 2014). Additionally, the presence of a legume creates of a favorable microbial community within the root zone (Yusuf et al. 2009).

2.2.4 Effect of Crop Rotation on Soil Physical Properties

Crop rotation can also lead to positive soil physical conditions in the soil. In rain-fed systems of agriculture, crop rotation plays an important role in water conservation and to some extent reduces challenges with soil salinity (Turner 2004). Although the interaction of NT and crop rotation are subtle and site specific and it is difficult the disentangle the contribution of each factor, the literature is replete with evidence of the positive influence of crop rotation. For example, Chan and Heenan (1996) observed that rotational effects on soil physical properties differed according to the crops in the rotation, and that the effect were likely related to these crops' different abilities to promote soil structure formation and soil structure stabilisation. Similarly, Salvo et al. (2010) reported positive effect of crop rotation on aggregate stability and particulate organic matter (POM) at different depths of soil. In another study, Lal et al. (1994) reported a significant interaction between tillage and crop rotation, with the least bulk density and greatest total porosity of 58% occurring in the rotated compared to the continuous monocrop treatments. The greatest infiltration rates have also been reported among crop rotations, for example, during maize vegetative growth in a soybean–wheat/clover–maize rotation (Katsvairo et al. 2002). As has been stated earlier, crop rotation increases biodiversity for both micro and macro-fauna which play an important role in soil structure formation. The deep legume taproots combined with abundant earthworm populations create burrows in the soil profile which can lead to increased soil porosity, gas exchange, and improved moisture distribution in the soil profile.

2.3 Effect of Crop Rotation on Pest, Disease and Weed Management

Crop rotation is an important pillar for breaking the soil borne pest and disease cycle (Jensen et al. 2010) especially under NT farming systems. No-till farming systems are characterized by *in-situ* crop harvest residue retention, which can increase the likelihood of pests and disease build-up and carry-over in succeeding seasons (Hobbs et al. 2008). Changing crops every season helps naturally break weed, insect, and disease cycles, thereby reducing the reliance on chemical pesticides, and protecting the environment. Crop rotation has shown some significant control effect on diseases such as grey leaf spot in maize, take-all in wheat, and sclerotinia in soybeans (Dordas 2008).

Crop rotation has also shown promise in tackling fall army worm, a recent menacing pest that has destroyed maize fields in sub Saharan Africa (Tambo et al. 2019). Under low-input systems of the tropics where farmers have limited access to capital (Sanginga and Woomer 2009), crop rotation is often the only economically feasible method for reducing insect and disease damage. A rotation cycle may replace a crop that is susceptible to a serious pest or disease with another crop that is not susceptible, or starve out the pest due to absence of a suitable host. For example, Rusinamhodzi et al. (2012) reported reduced *Striga* infestation in a maize crop following pigeonpea in central Mozambique. Moreover, maize in rotation with pigeonpea without added N yielded 5.6 Mg ha^{-1}, six times more than continuous maize, which was severely infested by striga (*Striga asiatica*) and yielded only 0.7 Mg ha^{-1} (Rusinamhodzi et al. 2012).

2.4 Scale-Appropriate Crop Rotation Options

2.4.1 Crop Rotation Design

The first step for any cropping system design is a comprehensive soil test for soil nutrient status (N, P, K, Mg, Ca, Zn, Mn), pH, and soil organic carbon (SOC). A crop rotation sequence is then planned based on production objectives, as well as addressing any concerns arising from the soil analysis. One of the strategies of a successful crop rotation is to grow a high N demanding crop such as maize following a legume crop to benefit from the positive N balance left by the legume. Deep rooted crops are needed to take up nutrients from deeper layers and cycle nutrients, especially the more soluble nutrients such as nitrates. Crop rotations that promote increased biomass and provide a slow release of nutrients to the root zone are also beneficial. A well-planned crop-rotation system can help farmers avoid many challenges associated with NT, such as increased soil compaction, perennial weeds, plant diseases, and slow early season growth.

Based on results in the literature, cereal-grain legume rotations are the most ideal for small farms, especially dual-purpose legumes that can play a significant role in nutritional diversity at the farm level (Franke et al. 2018). This is because the legume will produce edible leaves and grains – and sometimes mature earlier than the main crop, thus covering critical food deficit periods before the main crop is harvested (Mucheru-Muna et al. 2009; Rusinamhodzi et al. 2012).

2.4.2 Challenges of Effective Rotation Cycles

Crop rotation is easier to design and apply on large farms, and many of the challenges of crop rotation apply to small farms. Most smallholder farming systems do not allow systematic crop rotations due to a plethora of reasons. The major challenges hampering small farmers, especially in the tropics, from practicing successful crop rotation and maximizing the benefits are based on the following factors:

- Small land sizes - inadequate for multiple cropping in a single season;
- Multiple uses of legumes crops – leaves consumed leading to reduced residue retention;
- Crop-livestock integration – crop residues fed to livestock;
- Poorly developed markets for legumes – poor seed and/or fertiliser availability for legumes, and limited markets for the sale of crop produce;
- Differences in planting techniques – the different seed sizes of different crops may need different equipment; and
- Farmers perception of risk – the legume phase is considered a loss

While positive plot-level benefits of associations and rotations are known and widely reported, applying these under farmers' conditions seems to be problematic. It is clear that the economic returns for rotation are marginal, not least because of low yield but also because the support services sector, especially the output markets, are either poor or non-existent. Thierfelder et al. (2013) reported that in eastern Zambia, farmers grow maize in rotation with cowpeas on small plots and record increased maize yield after cowpea of between 20% and 30%, but the legume phase is economically challenging due to small returns. It has been reported that in most cases economic considerations and dysfunctional input and output markets for seed and produce are responsible for slow adoption of rotations (Snapp et al. 2002; Rusinamhodzi et al. 2017). It is therefore critical that the legume component is dual purpose for it to the integrated into the farming system.

Generally, small-scale farmers in sub-Saharan Africa allocate their priority land to food security crops (maize and sorghum) and legumes are only planted later and on about 10% of the land, which means only a small portion can be put under rotation. Dual purpose legumes are desirable, but if crop residue is extensively harvested, starting with the green leaves for food or feed and finally the grain for food, it can reduce soil quality benefits due to reduced biomass return to the soil. Availability of seed for both grain legumes and green manure cover crops is often problematic especially when the rotational crops have little extra benefits other than soil fertility increase or protection against soil erosion. A possible solution has been to use green manure cover crops (GMCCs), that are planted in rotation, and inter- or relay cropped with maize to increase soil cover and contribute N. However, these are not preferred by farmers because of (a) poor financial returns during the legume phase, (b) GMCC compete for water and nutrients with the main crop, and (c) dysfunctional input-output markets for most of the GMCCs.

In farming operations of any scale, high levels of crop residue contribute to cooler and wetter soils at planting and can interfere with seed placement, sometimes resulting in uneven crop stands. In addition, maize residues with wide C:N ratio can cause immobilization (Cadisch and Giller 1997). The contribution of residual N in these fields means through crop rotation is more critical, with some N needed at planting to avoid N deficiency early in the season (Williams et al. 2018). Too much residue also interferes with the performance of herbicides, resulting in poor weed control from pre-emergent herbicides (Araldi et al. 2015). In wheat systems, the wheat cycle sometimes leaves the soil hard or compacted, limiting the potential of the succeeding NT crop, most likely soybean, or too many years of NT can lead to build-up of pathogens requiring conventional tillage after a few years (Kirkegaard et al. 2014).

2.5 Conclusions

Crop rotations are needed to achieve good agronomic practices in general, but more critically are an important integral component of NT cropping systems and are responsible for improving nutrition, and pests and disease control. Cereal-grain legume rotations are the most ideal for small farms, especially the dual-purpose legumes which play a significant role in nutritional diversity at the farm level. However, limited landholdings prevent the widespread adoption of cereal-legume rotations for smaller farms. Large scale farmers have many crop rotations options, and they are able to make profit due to fuel and labor savings with NT in combination with cultivating cash legumes on a large scale. In the future, the design of crop rotations has to address the following issues, especially for small scale farmers (a) small land sizes; (b) multiple uses of legumes crops including leaves; (c) crop-livestock integration and use of crop residues as livestock feed; (d) poorly developed markets for legumes; (e) differences in planting techniques between legume and non-legume; and (f) farmers perception of risk. It is concluded that crop rotation is an integral component of good agricultural practice and is much more critical in NT systems where pests and diseases outbreak can be high, and additional N from nitrogen fixation needed.

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