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Diversification of Cropping Systems as an Approach to Enhancing Crop Productivity: A Review

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Abstract

Climate change could have negative consequences for agricultural production that generated a desire to build resilience into agricultural systems. One rational and cost-effective method may be the implementation of increased agricultural crop diversification. Crop diversification can improve resilience in different ways: by engendering a greater ability to suppress pest outbreaks and dampen pathogen transmission, increasing natural enemies, agroecology conservation, soil fertility management, which may worsen under future climate scenarios, as well as by buffering crop production from the effects of greater climate variability and extreme events. *It* can be implemented in a variety of forms and at a variety of scales, allowing farmers to choose a strategy that both increases resilience and provides economic benefits. Furthermore, relative to mono cropping systems, the vast majority of diversification systems have either neutral or positive effects on productivity crops, and either reduce or have neutral effects on crop income volatility. From an agronomic point of view, crop rotation and intercropping play important roles in food security, climate resilience, soil fertility management, agroecology conservation, discouraging insect pests, and increasing natural enemies. Therefore, developing countries must be part of any diversification strategy to enhance crop productivity.

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Introduction

Crop diversification can be considered as an attempt to increase the diversity of crops through, e.g., crop rotation, multiple cropping, or intercropping compared to specialized farming to improve the productivity, stability, and delivery of ecosystem services (Wezel *et al.*, 2014). It can be one measure to develop more sustainable production systems, develop value-chains for minor crops (Meynard *et al.*, 2018), and contribute to socio-economic benefits (Feliciano, 2019). Crop diversification practices can include higher crop diversity, more diverse crop rotations, mixed cropping), cultivation of grain legumes in otherwise cereal-dominated systems (Watson *et al.*, 2017), perennial leys or grassland, and regionally adapted varieties or various mixtures. Crop diversification and/or additional diversification measures such as changing seeding times or cropping patterns have the potential to lead to higher and more stable yields, increased profitability, and increased agro ecosystem resilience over time (Rosa-Schleich *et al.*, 2019; Meynard *et al.*, 2018).

These practices have the potential to make cropping systems more diverse in space, time, and genetics. Consequences of diversification are temporal shifts and ranges of phonological stages (relevant for biodiversity and adaptation to climate change), more frequent or continuous soil cover, and more diverse management strategies that reduce labor peaks and economic risk. Davis *et al.,* (2012) showed that diverse cropping systems provided similar or even higher yields than simplified systems, whilst environmental impacts were lower. Arable crop species diversity at the national level is correlated with greater year-to-year stability of the total national harvest of all edible crops. Nevertheless, measures of diversification are rarely implemented because of a lack of required investments in machinery, infrastructure, and expertise (Meynard *et al.,* 2018).

According to Kremen *et al., (*2012) and Rosa-Schleich *et al.,* (2019), a very complex diversification approach to diversified farming systems relies on diversification concepts that apply to individual steps of crop diversification. The choice of the combination of measures seems to rely on diversity concepts and depends on which ecosystem services (ES) are in focus. In many cases, the concept of diversity is seen as synonymous with the concept of diversification. From an agronomic point of view, crop rotation or mixed cropping might lead to higher biodiversity and associated ecosystem services. Crop diversification can lead to greater genetic and/or structural diversity in time and/or space. Common examples of crop diversification are crop rotations, double cropping or intercropping, bee crops, nurse crops or various mixtures.

Diversification by agronomic measures, e.g. tillage, shall not be considered unless it is tested in combination with crop diversification. I argue that a common understanding of the diversification concept in the context of crop production is needed for enabling the comparison of results and to enhance the empirical evidence of the effects of diversification as a measure to make cropping systems more resilient and to reduce negative impacts on the environment.

The main objectives of this study to review on cropping systems diversification as an approach to enhancing crop productivity

Diversification of cropping systems

Crop diversification is the practice of cultivating more than one variety of crops belonging to the same or different species in a given area in the form of rotations and or intercropping. It is perceived as one of the most ecologically feasible, cost-effective, and rational ways of reducing uncertainties in agriculture, especially among smallholder farmers (Joshi, 2005). Also, crop diversification increases resilience and brings higher spatial and temporal biodiversity on the farm (Holling, 1973; Joshi, 2005). Crop diversification, according to Lin (2011), improves soil fertility, pest and disease control, yield stability, nutrition diversity, and health. It can also serve as a superior substitute for the use of chemicals to maintain soil fertility and control pests. Truscott *et al.,* (2009) consider crop diversification an environmentally sound alternative to the control of parasites and the maintenance of soil fertility in agriculture. Diversified cropping systems, in general, tend to be more agronomical stable and resilient. This resilience is mainly because they are usually associated with reduced weed and insect pressures, reduced need for nitrogen fertilizers (especially if the crop mix includes leguminous crops), reduced erosion (because of cover crops' inclusion), increased soil fertility, and increased yield per unit area (Lin 2011).

Moreover, diversified cropping systems can also provide habitats for beneficial insects, and this can help reduce the number of pests by rendering host crops less attractive for parasitic infestations. According to Shoffner and Tooker (2012), the increasing popularity of crop diversification is owing to its support for species mixtures over monoculture, which offers reasonable ways of controlling pests and diseases. It also addition of new crops or cropping systems to agricultural production on a particular farm taking into account the different returns from value-added crops with complementary marketing opportunities. Crop diversification provides better conditions for food security and enables farmers to grow surplus products for sale at market and thus obtain increased income to meet other needs related to household well-being. Crop diversification can enable farmers to gain access to national and international markets with new products, food and medicinal plants. Diversifying from the monoculture of traditional staples can have important nutritional benefits for farmers in developing countries and can support a country to becoming more self-reliant in terms of food production. Diversification can also manage price risk, on the assumption that not all products will suffer low market prices at the same time. Compared to producing monocultures, management techniques for diversified crops generally consist of more sustainable natural resource practices. Crop mixtures are most likely to work by increasing natural enemies of insect pests, interrupting disease cycles, suppressing weeds and volunteer crop plants, and/or making pest and disease pathogen penetration more difficult. Also, crop diversification can contribute to local biodiversity, especially when farmers grow indigenous crop varieties. Soil fertility improvement as one of the benefits of crop diversification is the foundation of sustainable and productive farming systems (Lin, 2011).

Well-managed soils help lower pest pressure, optimize water use by plants, and improve overall crop yields. Moreover, there is also some opinion that crop diversification has a positive impact on climate change effects through the ability of local flora (as opposed to monoculture) to hold carbon, thus generating less carbon dioxide. It therefore implies that crop diversification contributes in one way or the other to all the three main principles of CSA by improving; productivity, livelihood outcomes, and resilience of farming systems and reducing carbon dioxide emissions. Increasing diversification of cereal cropping systems by alternating crops, such as oilseed, pulse, and forage crops, is another option for managing plant disease risk (Krupinsky *et al.*, 2002).

Poly culture/ Multiple cropping/

Poly culture has traditionally been the most prevalent form of agriculture in most parts of the world and is growing in popularity today due to its environmental and health benefits. According to Truscott *et al.,* (2009), there are many types of poly culture, including annual poly cultures such as intercropping and cover cropping and integrated aquaculture. Poly culture is advantageous because of its ability to control pests, weeds, and diseases without major chemical inputs. As such, poly culture is considered a sustainable form of agriculture. However, issues with crop yield and biological competition have caused many modern major industrial food producers to continue to rely on monoculture instead. Poly culture efficiently utilizes land, water, and fertilizer, which results in more crops being produced and more profitable farm production.

Intercropping

Intercropping is the simultaneous cultivation of more than one crop species on the same piece of land and is regarded as the practical application of basic ecological principles such as diversity, competition and facilitation (Hauggaard-Nielsen *et al.*, 2007). In this system, an additional crop is planted in the unused spaces throughout the main crop in the field. Intercropping allows the farmer to grow more than one type of crop on the same piece of land and at the same time. Intercropping improve soil fertility through nitrogen fixation by the component legume (Hauggaard-Nieson *et al.*, 2001), efficient use of environmental resources (Knudsen *et al.*, 2004), reducing damages caused by insect pests, diseases and weeds (Banik *et al.*, 2006), and improvement of forage production and quality (Bingol *et al.*, 2007).

According to (Yildirim and Guvenc, 2005) reported that benefits of intercropping systems are increasing the productivity and profitability. Intercropping also has been shown to decrease the risk of crop failure by increasing the crop yield stability over time and across locations (Bybee-Finley *et al.*, 2016). Crop yield stability can be increased by reducing the variation over years at the same site, or by increasing the production consistency throughout the year. Most research findings showed that yield of intercropping is often higher than sole cropping (Zhang and Li, 2003). This is mainly due to resources such as water, light and nutrients can be utilized more efficiently in intercropping than in sole cropping (Malezieux *et al.*, 2009).

The underlying principle of efficient resource use in intercropping is that, if crops differ in the way they utilize environmental resources when grown together, they can complement each other and make better combined use of resources than when they are grown separately (Ghanbari-Bonjar, 2000).

However, the success of intercropping systems is due to an enhanced temporal and spatial complementarily of resource capture, for which both aboveground and belowground parts of crops play an important role (Wu *et al.*, 2012). Therefore, intercropping seems relevant management options in improving the efficiency of this system.

Maximum yield of the component crops in an intercropping can be achieved by minimizing competition effects through appropriate planting pattern and timing of intercropping based on growth characteristics and requirements of the component species (Banik *et al.*, 2006). Even though, such agronomic options seem easily controllable management factors, their effects on intercrop yields need to be well understood and determined experimentally. Enhancing productivity of cereals and legume intercrops requires improving the interspecies complementarily or reducing competition effects. This might be achieved through manipulation of plant arrangements, plant densities, relative planting dates and planting compatible cultivars (Mutungamiri *et al.,* 2001).

Rotation of crops

Crop rotation is defined as the practice of growing a sequence of plant species on the same land (Bullock 1992). Crop rotation is characterized by a cycle period, while crop sequence is limited to the order of appearance of crops on the same piece of land during a fixed period (Leteinturier *et al.*, 2006). Component crops are so chosen so that soil health is not impaired. or it means growing a set of crop in a regular succession on a piece of land in a specific period of time, with an object to get maximum profit least investment without impairing soil fertility. Crop rotation is along used concept in models to represent the temporal dimension of cropping plan decisions (Heady, 1948).Because the succession of crops in a given area has effects on production and consequently on cropping plan decisions, the traditional approach developed by agronomists was to derive cropping plans from the crop proportions in crop rotation.

Some authors (e.g. Maxime *et al.*, 1995; Dogliotti *et al.*, 2003) reported that the reproducibility of a cropping system over time is only ensured when crop choices are derived from crop rotation. Cropping plan decisions consequently require one to look back and forth in time. Crop rotation as a particular crop sequence is therefore a natural starting point in designing cropping systems that are stable over time (Vereijken, 1997). Crop rotation is considered as being essential for integrated farming (Stoate *et al.*, 2001) and is in contradiction with mono cropping as a sustainable solution for farms (Leteinturier *et al.*, 2006). The concept of crop rotation is an interesting means of obtaining a succession of crops year after year on a specific piece of land. It offers the potential of attenuating the environmental impacts of agriculture while maintaining production and achievements over the years (Vandermeer *et al.*, 1998). Crop rotations are also used for breaking weed and disease cycles, controlling erosion and for reducing dependence on external inputs (Bullock, 1992). It also provide adequate residue cover reduce nutrient leaching, soil erosion and weed competition (Kurtz *et al.*, 1984). The beneficial effects of biologically fixed N by legumes on cereals have been the most important criteria for including crops in rotation systems (Peoples *et al.*, 1990). However, the concept of crop rotation provides very limited insight into the organization of crops among different and heterogeneous pieces of land. Cover crops and green manures are also part of the crop rotation in many sustainable land management systems.

A cover crop is any crop that is grown to provide soil cover, regardless of whether it is later incorporated into the soil or not. Cover crops are grown primarily to prevent soil erosion. Crop rotations that include cover crops, perennial grasses and legumes, and reduced tillage are an important factor in SOM management and can be adapted to any cropping system. Crop rotations that maximize soil C inputs and maintain a high proportion of active C are important factors in establishing a sustainable cropping system. In general, it creates better growth conditions for plants, thus achieving higher and quality yields while protecting the environment. There are many reasons why farmers should include crop rotation in their crop production: Reduce the risk of insect pest and disease attack by improving soil nutrient utilization; different crops take different nutrients from the soil, affecting soil fertility, alternative sources of soil nitrogen. A better balance of the fertility demands of various crops avoids excessive depletion of soil nutrients.

Reduced risk of agricultural chemical contamination of water and preservation of biodiversity Aiming to provide enough food for the growing population, a few aspects must be considered; available farmland, farm technology, and the crop production system. Since much of the world's arable land is already in crop production, the only solution is in the proper selection of a crop production system, one such as poly culture, as well as the farm technology used, such as precise machinery, drones, crop sensors, smart irrigation, and modern farm management software. Farmers practice poly culture crop production in order to minimize production risks and ultimately provide a stable source of income and nutrition while at the same time maximizing economic and energy returns using primarily local farm technology. Be part of those who manage sustainable farming to provide a better livelihood for future generations.

Crop diversification for sustainability

Diversification of agriculture refers to the shift from the regional dominance of one crop to regional production of a number of crops, to meet ever increasing demand for cereals, pulses, vegetables, fruits, oilseeds, fibres, fodder and grasses, fuel, etc. It aims to improve soil health and a dynamic equilibrium of the agro-ecosystem. Crop diversification takes into account the economic returns from different value-added crops. It is different from the concept of multiple cropping or succession planting, in which multiple crops are planted in succession over the course of a growing season. Moreover, it implies the use of environmental and human resources to grow a mix of crops with complementary marketing opportunities, and it implies a shifting of resources from low value crops to high-value crops, usually intended for human consumption such as fresh market fruits and vegetables.

With globalization of the market, crop diversification in agriculture means increasing the total crop productivity in terms of quality, quantity, and monetary value under specific, diverse agro-climatic situations world-wide.

Diversified farms are usually more economically and ecologically resilient. While monoculture farming has advantages in terms of efficiency and ease of management, the loss of the crop in any one year could put a farm out of business and/or seriously disrupt the stability of a community dependent on that crop. By growing a variety of crops, farmers spread economic risk and are less susceptible to the radical price fluctuations associated with changes in supply and demand.

Crop diversification and climate-smart farming

Climate change is emerging as one of the major threats to development across the African continent (Nyasimi *et al.*, 2014). Agriculture is one of the sectors significantly affected by climate change and variability. Seasonal dynamics, increased frequency of droughts, increased temperatures, and altered patterns of precipitation and intensity are some of the extreme weather events evident in southern Africa.

Declining crop yields, increased agricultural risks, diminishing soil fertility, and environmental degradation are some of the main challenges that continue to threaten societal goals of improving food, income, and nutrition security, especially in smallholder farming. It, therefore, calls for a significant transformation in African agriculture, especially in the worst affected regions like Southern Africa, to withstand the emerging challenges.

An acceptable and meaningful transformation will be expected to improve productivity, build resilience in farming systems, improve livelihoods, and reduce harm to the environment (Nyasimi *et al.*, 2014). However, climate change adaptation research in agriculture has identified climate smart agriculture (CSA) as one of the many sustainable agricultural practices (SAPs) that can help households withstand the deleterious effects of climate change and variability in smallholder farming systems (Manda *et al.*, 2016). Hundreds of technologies, practices, and approaches fall under the heading of CSA. Crop diversification through rotations and intercropping; agroforestry; conservation tillage; cultivation of drought-resistant crops; water harvesting; and integrated soil fertility management are examples of critical practices and techniques (Faurès *et al.*, 2013).

CSA is an integrated approach to the implementation of agricultural development programming policies that endeavors to improve productivity, livelihood, and environmental outcomes (Rosenstock *et al.*, 2016). Experts, policymakers, and other stakeholders concerned about the impact of adverse externalities generated by climate change on welfare, food, and nutrition security have largely recommended CSA adaptation as an essential vehicle to better the livelihoods of vulnerable segments of the population. CSA is the commonly preferred method to deal with the deleterious consequences of climate change and variability in the smallholder farming sector (FAO, 2010; World Bank, 2014).

Moreover, it is considered sustainable and a certain practice as it strengthens resilience in smallholder agricultural systems. Its adoption as an adaptation strategy is expected to help smallholder farmers adapt to climate change and variability by intensifying and or diversifying their livelihood strategies.

CSA is premised on three main principles. These include (1) mitigating climate-related risk while improving food, income, and nutrition security; (2) achieving productivity and livelihood benefits; and (3) having area-specific technologies that are appropriate for the specific areas in which they are used (Rosenstock *et al.*, 2016). Where possible, CSA also aims to reduce greenhouse gas (GHG) emissions, mainly through enhancing the carbon sink (vegetative cover) (Lipper *et al.*, 2014).

The important question is whether CSA technologies at the farm level significantly contribute to crop resilience (adaptive capacity), climate change mitigation, and productivity. Crop diversification is not a new practice. The birth of a new challenge in agriculture, "climate change", has made it attain popularity as embracing it may significantly reduce risks associated with agricultural production, improve productivity, food security, income, and nutrition in smallholder farming systems.

Crop diversification and productivity

There is a significant impact of crop diversification on cereal crop productivity. This implies that diversified cropping systems, including cereal and legume intercrops, can improve the productivity of the principal crop. This could be as a result of the improved soil fertility in legume and cereal mixtures. Smith and Read (2008) found diversity through crop rotations of greater cover crops and nitrogen-fixing crops to increase the yield of the primary crop. The main probable option for improvement in crop productivity with diversification is that crop mixtures are more likely to be effective in suppressing diseases and pests, increasing soil fertility and improving the efficiency of local agro-ecological systems. In the literature, diversified cropping systems, they have been found to work in raising productivity by increasing natural enemies of insects and pests, breaking disease cycles (Larkin *et al.,* 2010; Ojaghian *et al.,* 2012), suppressing weeds and volunteer crop plants (Campiglia *et al.,* 2010), modifying the microenvironment within the crop canopy and or making pest and disease penetration more difficult (Krupinsky *et al.,* 2002; Lin, 2011). Crop diversification is critical for smallholder farmers in adapting to climate change and variability because it reduces the severity of a number of challenges in smallholder farming systems, thereby aiding in the development of long-term resilience to climate variability and change.

Income and crop diversification

Crop diversification significantly improves income from agricultural activities. Increased production from diversified cropping systems and increased production stability are the probable explanations for improved income as a result of crop diversification. This is an important finding considering that climate change and variability reduce crop yields and increase susceptibility to total crop failure. Adopting a more diversified cropping system is therefore an important adaptation option as it reduces production risks, hence improving production stability.

Diversification of crops and food security

Crop diversification has a positive and statistically significant impact on food security and nutrition indicators (food consumption score and household dietary diversity). This implies that besides improving productivity, increasing production and income stability, crop diversification also has a direct effect on food availability and nutrition. This is mainly because crop diversification will improve yields, bring crop yield stability and also have a crop insurance effect (Yachi and Loreau, 1999), since if one crop fails, the farmer can depend on the other crop. This will have a direct impact on food security and nutrition in smallholder farming systems since, traditionally, the main aim will be to sustain the family and sell surplus where possible. This makes crop diversification a more important climate smart option as improving food security and diet options will help in building resilience to intensifying climate change and variability effects by smallholder farmers. According to Mugendi Njeru (2013), crop diversification not only allows more efficient utilization of agro-ecological processes but also provides diversity for the human diet and improves income, which improves the purchasing power for the household for buying other foods.

Research and Developmental Support for Crop Diversification

Future agriculture will be much more knowledge and skill-based than traditional subsistence agriculture. In the wake of globalization and the opening up of the global market, there will be many more opportunities for entrepreneurship development in agriculture. This also calls for paradigm shifts in research and technology development and also the transfer of technology for successful crop diversification. The research system must not only address the issues associated with persistence, indulgence, and knowledge in the areas of emerging technologies, but also create a cadre of scientists through continuous skill upgrades and human resource development. The researchers also need to popularize the technologies, impart knowledge and skills to the extension functionaries for the transfer of technologies to the farmers. This knowledge-based farming will call for much more interaction between researchers, extension workers, and farmers. The fruits of innovative technologies should reach farmers as soon as possible and spread as widely as possible.

Agricultural intensification increased crop productivity but simplified production with lower diversity of cropping systems, higher genetic uniformity, and a higher uniformity of agricultural landscapes. The associated detrimental effects on the environment and biodiversity, as well as the resilience and adaptability of cropping systems to climate change, are of growing concern. Crop diversification may stabilize productivity of cropping systems and reduce negative environmental impacts and loss of biodiversity, but a hard understanding of crop diversification, including approaches towards more systematic research, is lacking. Crop diversification has been considered an important strategy to stabilize farming income and enhance food security. With agro biodiversity being a strategy to mitigate fluctuation risk, emphasis should be placed on risk prone environments (low potential) by promoting the cultivation and maintenance of diverse crop species. To achieve this requires the enabling of agro-ecological-specific technical or institutional services that support diversification. Among these services, the identification and promotion of crop species with better adaptive capacity as well as economic, environmental, and social benefits are important.

Determining crop sequencing in the case of rotation and the appropriate level of inputs used to avoid nutrient competition among crops in the case of intercropping. In order to reverse the negative relationship between crop productivity and crop diversification, the maximum number of crops that a farm household can effectively manage, accompanied by appropriate technical options, needs to be determined based on farmers' experience and/or scientific evidence. The merits of crop diversification that explain the positive association with crop productivity, crop income, food security and nutrition include its ability to; improve soil fertility, suppress diseases and pests (by increasing natural enemies of pests and breaking disease cycles); suppress weeds and volunteer crops, improve efficiency of agro-ecological systems, which in turn reduces crop production risks, improves production stability, yields, crop income; and diversity of the human diet. Therefore, crop diversification plays important role in climate change resilience smallholder farming systems in the region.

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