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Exploring intercropping as a sustainable system approach for smallholder farming: A literature review

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Abstract

Global food shortage is known to be caused by increasing population, adverse weather conditions, droughts, and poor food distribution. The bulk of this population reside in rural areas of Sub-Saharan African countries, with large numbers experiencing food insecurity. Industrialized farming has contributed significantly to the food supply but has a harmful effect on the environment due to the intensive use of chemical fertilizers which deteriorates soil and water quality. As a result, intercropping, the planting of two or more crop species simultaneously in the same field area is now being re-evaluated as a sustainable system approach for smallholder farmers. Smallholder farming employs more rural people and uses fewer external inputs for production which have less impact on the environment compared to mechanized agriculture, making them more suitable for sustainable farming. This paper evaluated relevant research done on intercropping systems and identified gaps for future research. Overall, the studies, through a series of experimental trials have proven that intercropping systems can increase crop yield, stability, and net income and produce low carbon footprint compared to the traditional monoculture. The system, however, has some disadvantages, such as yield reduction of the main crop due to competition, higher cost of maintenance in weeding, and damage to other crops during harvesting. There is also limited to no data investigating the economic viability and adoption of intercropping. These are major concerns that need to be investigated to obtain optimum benefits from the system and allow a steadily transition into a green economy.

Keywords: *Intercropping, Sustainable System, Smallholder Farming, Sub-Saharan Africa, Literature Review.*

1. INTRODUCTION

Global food security is one of the most crucial issues facing the world's population. According to a new United Nations report, the world population is projected to exceed approximately 8.6 billion in 2030, 9.8 billion in 2050 and 11.2 billion in 2100 (United Nations Department of Economic and Social Affairs, 2022), which is expected to double the global demand for food crops. The fastest population growth is projected for Sub-Saharan Africa, and a slower population growth rate for Asia, Latin America and the Caribbean and relatively little change in population numbers for Europe and Northern America (United Nations Economic and Social Council, 2021). Other than the rising population; adverse weather conditions, droughts, poor food distribution, and low food production are some of the causes of food insecurity in the Sub-Saharan region (Tsubo *et al*., 2003).

The agricultural sector in the Sub-Saharan region is dominated by smallholder farming which is characterized by limited access to infrastructure, inputs, and markets, and often has access to less than two hectares of land (von Loeper *et al*., 2016). However, evidence depicts that an effectively producing smallholder farmer is seen as an essential route out of poverty (Page and Slate, 2003). Smallholder farming employs many more rural people and uses fewer external inputs for production which have less impact on the environment compared to mechanized agriculture (UNCTAD, 2013, UNEP-UNCTAD, 2007; and Altieri, 2009), making them more suitable for sustainable farming.

According to Blignaut *et al*. (2014), a transition to a green economy is increasingly taking place in South Africa, however more qualitative and quantitative research into sustainable agriculture should be developed. Sustainable agriculture is a type of agriculture that makes use of resources efficiently for the benefit of the environment and human population. Its objectives are to provide increased food security, with increased quality and quantity while considering the needs of future generations; conservation of water, soil, biodiversity, and natural resources; maintain and increase farmers' profitability and maintain the development of rural communities (Eskandari, 2012). Thus, for an agricultural system to be considered sustainable; it should be ecologically suitable, economically justified and socially desirable. For this reason, immense attention has been given to the contribution of intercropping as a sustainable system to increase and exploit biodiversity, reduce the dependence of fertilizers and agrichemicals to increase output, adaptation to and mitigation of climate change and supporting low-input and organic agricultural systems (Weih *et al*., 2022).

Intercropping, the planting of two or more crop species simultaneously in the same field area, has been widely practiced worldwide (Wang *et al*., 2014). In the former days, intercropping was preferred by farmers over mono-cropping (Filho *et al*., 2011). However, the modernization and industrialization of agriculture, caused a shift towards sole cultivation of various crop species with the aim of increasing food production. An environmentally harmful aspect of a modern and industrialized agriculture is accompanied by the intensive use of fertilizers which deteriorates soil and water quality and disrupts the global nitrogen cycle through the emissions of reactive gases such as ammonia and nitrogen oxides (Fung *et al*., 2019). According to Tubiello *et al*. (2013), agriculture is the largest emitter of N_2O (nitrous oxide) and second largest emitter of CH4 (methane). The sector alone contributes 10 to 25% of the global

greenhouse gas emissions annually through production practices and land management (Scialabba and Muller-Lindelauf, 2010). As a result, the intercropping system is now being re-evaluated due to its benefits and the disadvantages associated with mono-cropping.

The main reason for promoting intercropping system for smallholder farming is because it involves the integration of crops using space and labour efficiently. Biophysical benefits include better use of environmental factors, higher yield stability in varying environments and conservation of soil fertility. Socio-economic benefits include on-farm diversity, increased productivity, and reduction in farm risk (Sharaby *et al*., 2015).Thus, as part of its mission to foster innovation to support and develop the agricultural sector; the Agricultural Research Council (ARC) forms part of the European's Horizon 2020 programme, which was awarded to 21 European and African Research and Development organisations for an envisaged project, with the ARC as the lead organisations in South Africa. The Revenue Diversification in Africa through bio-based and circular Agricultural Innovations (DIVAGRI) project addresses limitations of smallholder agricultural systems where farmers lack the means to invest in improving productivity, making them vulnerable to food insecurity, and unsustainable practices that impact negatively on the environment.

The DIVAGRI project proposes a wide range of bio-based innovative solutions adapted to specific conditions in target countries. As part of the project's initiatives, the ARC is responsible for the development and promotion of intercropping of different crop species to smallholder farmers. On-farm field demonstrations and trials at the ARC experimental farm are still underway, and subsequently after pilot results (and adapting to local conditions) the impact of intercropping systems on yield, stability, revenue, and welfare of farmers will be assessed using econometric based models.

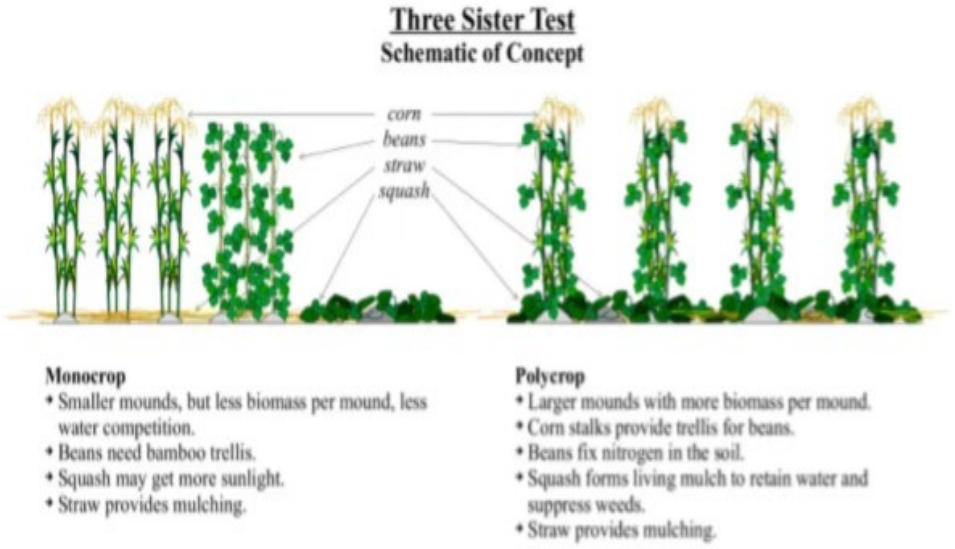

Figure 1: A schematic of concept illustrating mono-cropping system versus intercropping system. Source: lowtechinstitute.org [Accessed March 2023]

2. LITERATURE REVIEW

2.1 Definition of terms:

2.2.1 Intercropping: is a multiple cropping system in which two or more crops are planted together on the same piece of land, during their growing season (Weih *et al.*, 2022). This contrasts with mono-cropping in which a single crop is cultivated in a given area. Intercropping can include annual plants with annual plants intercrop, annual plants with perennial plants intercrop, and perennial plants with perennial plants intercrop (Mousavi and Eskandari, 2011).

The intercropping system is divided into the following groups (Maitra *et al*., 2021):

a) **Strip-intercropping**: this is the cultivation of two or more crops at the same time in strips/rows allowing crop interaction and independent cultivation.

Advantages:

- In strip intercropping, there is no competition for light, water and soil nutrients.

b) **Mixed intercropping**: this is the process of growing two or more crops simultaneously with limited or no arrangement.

Advantages:

- The basic objective of mixed intercropping is minimization of risk and insurance against crop failure due to external factors such as adverse weather conditions.

c) **Relay-intercropping**: it is an intercropping system in which the succeeding crop (next crop) is planted when the first crop (preceding crop) has reached its physiological maturity stage just before harvesting.

Advantages:

- Minimum tillage is required for relay cropping and the primary cost of cultivation is less.
- Crop residues are added in the soil which increases soil organic matter.
- Residual fertilizer of previous crop benefits for succeeding crop.
- Weed infestation is less, as the cultivation area is engaged with crops all year round.

2.2 Literature from other sources

Intercropping has recently been hypothesized to enhance crop yield through a variety of econometric models by various scholars. A study by Madembo *et al*. (2020) assessed the productivity and stability of maize-legume intercropping systems for smallholder conservation

agriculture in one of the Sub-Saharan African countries; Zimbabwe. The methodology in place included a three-year study in on-farm and on-station trials using mixed modelling, best linear unbiased predictors estimation, additive main effects and multiplicative interaction models for data analysis. Sole cropping was compared to intercropping of different grain legumes, green manures and fertilizer application on crop yield and stability. In general, the results highlighted that total yield system of intercrops out-yielded sole maize cultivation in most environments for both on-farm and on-station trials which signifies the ability of intercrops to enhance cropping system yield. Moreover, intercropping cowpea with jack bean, as well as maize with pigeon pea was more stable in all environments compared to maize sole cropping. Intercropping has proven to be a more viable option for sustainable smallholder farming. Unexpectedly, the results also depicted that legume intercropping with fertilizer application improved the stability of the systems. This contradicts Raseduzzaman's (2016) study, which also assessed the ability for intercropping to enhance yield stability and ensure food security in comparison to mono-cropping using meta-analysis and field experiments. The work highlighted that fertilizer application has no strong effect on intercrop yield, and instead increased grain and biomass yield, but reduced the pea yield.

Intercropping systems can also be practiced with integrated farming, which produces both crops and animals on one farm to allow wider crop rotations and thus reducing dependence on chemicals, permitting diversification for better risk management. Industrialized farming in developed countries has managed to increase global food supply, however the excessive use of mechanization, fertilizers and pesticides has had negative environmental impacts (Zhang *et al*., 2015; Chen *et al*., 2014; Cui *et al*., 2018). The research by Chai *et al.* (2021) evaluated the effectiveness of combing integrated farming with relay intercropping system to increase food production and reduce environmental footprint. They developed an integrated farming system that incorporated four components: a) intensified cropping through relay planting or intercropping, b) within field-strip rotation, c) soil mulching with available means, d) no-till or reduced till. Sixteen field experiments were conducted over 12 consecutive years (2006 to 2017). The results of the study revealed that the integrated farming system with intercropping generates more benefits in terms of crop yield, farm net returns and reduction in environmental footprint compared to conventional monoculture farming system. Two relay systems, pea + maize and wheat + maize, along with sole pea, sole wheat, and sole maize, were arranged in randomized complete block designs. A total of 16 field experiments were conducted to test relay-planting systems and the corresponding monoculture crops under various treatments which include the rate of nitrogen fertilizer, irrigation amount, mulching practices with crop straw, and maize planting density. These treatments were designed to determine the possible mechanisms involved in the advantage of relay planting compared to monoculture cropping. The results further suggested that relay intercropping enhanced water and fertilizer use efficiency, with high root length density for relayed maize and greater root surface area density compared to maize sole cultivation. Moreover, *crop yield* of relay intercropping over the corresponding mono-cropping yield was calculated using the yield advantage equation. To calculate *financial returns*, the cost of each input used was recorded for each treatment annually and then averaged across all the years to get net returns. Finally, greenhouse gas emissions

were used as a proxy to estimate the *environmental footprint* using country-specific empirical modelling.

3. CONCLUSION

In general, the review provided a series of experimental trials conducted by researchers which have proven that intercropping systems can increase crop yield, stability, and net income and produce low carbon footprint compared to the traditional monoculture. Intercropping ensures multiple benefits such as enhancement of food production, environmental and income security, production sustainability and ecosystem services. These are all beneficial in an ever-increasing global demand for food, as well as over-population and food insecurity faced by many smallholder farmers in Africa, Sub-Saharan countries in particular. The review has also shown that legumes are important component crops in intercropping system that play adaptable roles in biological nitrogen fixation and soil quality improvement, enhancement of environmental quality by reducing the dependence on chemical nitrogen fertilizer application (Maitra *et al*., 2021) (although one study found fertilizer application to be beneficial in both intercrops and mono-cropping), additional yield output including protein yield and creates functional diversity.

There are, however, some flaws in intercropping. It is said that the yield of the main crop in intercropping system is not as high compared to in monoculture, because of competition among intercropped plants for soil nutrients and water (Willey, 1979). This yield reduction may have a negative economic impact if the market price for the main crop is higher than the other intercropped plants (Gebru, 2015). Furthermore, the system requires higher cost of maintenance in weeding which must be done by hand. This may not pose a problem for smallholder farmers who are more labour intensive and use family labour for food production in comparison to commercial farming that must source and pay for labour costs. Finally, harvesting of one crop may cause damage to the other (Gliessman, 1985). These are major concerns that need to be investigated to obtain optimum benefits from intercropping systems.

It is evident that there is limited to no research data investigating the economic viability of intercropping to determine whether the system's economic benefits exceed its economic costs, when analysed for the well-being of smallholder farmers. There is also a research gap on the factors influencing the adoption of this system by smallholder farmers. An overall impact assessment using econometric models to advance and add on literature is underway at the ARC experimental farm.

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