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Potential of agroforestry in improving soil productivity in semi-arid farming regions of Zimbabwe

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ABSTRACT

Crop productivity in semiarid regions is constrained by low inherent soil fertility and limited moisture. A large (>70%) proportion of communal farmers is located in semi-arid regions, which are characterized by erratic rainfall and infertile and acidic soils with poor water-holding capacity. Low soil moisture recharge, high evapotranspiration, and reduced nutrient content drastically reduce crop yields, exposing the rural population to acute food and nutrition deficiencies. Low soil productivity is exacerbated by a lack of adequate farming resources among communal farmers. Farmers cannot afford to purchase expensive soil fertility-improving inputs, such as chemical fertilizers, and are devoid of irrigation infrastructure. Hence, sustainable in-field soil moisture and fertility conservation strategies are required in the semiarid regions of Zimbabwe. Many strategies, such as straw mulching, conservation agriculture (CA), fanya juu, crop rotation, and agroforestry (AF), are possible strategies for enhancing soil moisture conservation and fertility. Considering the rampant deforestation in the semi-arid communal areas of Zimbabwe, the AF is potentially important in restoration of soil production. The AF is when farmers intentionally integrate multipurpose trees with field crops and/or animals in their farms to boost productivity. Agroforestry increases soil productivity by improving soil moisture holding capacity, fertility, and soil conservation. Unfortunately, the potential of AF in agro-systems is limited, and hence, there is low uptake among smallholder farmers in Zimbabwe. Therefore, this review explores the ways in which agroforestry can be used to increase soil productivity in semiarid regions.

Keywords: Adoption, climate change, drought, low fertility, multi-purpose trees, Zimbabwe

RÉSUMÉ

La productivité des cultures dans les régions semi-arides est limitée par la faible fertilité naturelle des sols et la disponibilité réduite en eau. Une grande proportion (>70%) des agriculteurs communautaires se trouve dans ces régions caractérisées par des précipitations erratiques et des sols infertiles et acides avec une faible capacité de rétention d'eau. La faible recharge en humidité du sol, la forte évapotranspiration et la réduction de la teneur en nutriments diminuent considérablement les rendements des cultures, exposant la population rurale à des déficiences alimentaires et nutritionnelles aiguës. La faible productivité des sols est exacerbée par le manque de

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ressources agricoles adéquates parmi les agriculteurs communautaires, qui ne peuvent pas se permettre d'acheter des intrants coûteux pour améliorer la fertilité des sols, comme les engrais chimiques, et ne disposent pas d'infrastructures d'irrigation. Par conséquent, des stratégies durables de conservation de l'humidité et de la fertilité des sols sur le terrain sont nécessaires dans les régions semi-arides du Zimbabwe. De nombreuses stratégies, telles que le paillage avec de la paille, l'agriculture de conservation (AC), le fanya juu, la rotation des cultures et l'agroforesterie (AF), sont des solutions possibles pour améliorer la conservation de l'humidité du sol et la fertilité. Compte tenu de la déforestation rampante dans les zones communautaires semi-arides du Zimbabwe, l'agroforesterie est potentiellement importante pour la restauration de la productivité des sols. L'agroforesterie consiste à intégrer intentionnellement des arbres à usages multiples avec des cultures de champs et/ou des animaux dans les exploitations agricoles pour augmenter la productivité. L'agroforesterie augmente la productivité des sols en améliorant la capacité de rétention de l'humidité, la fertilité et la conservation des sols. Malheureusement, le potentiel de l'agroforesterie dans les systèmes agricoles est limité, ce qui entraîne une faible adoption parmi les petits exploitants agricoles au Zimbabwe. Par conséquent, cette revue explore les moyens par lesquels l'agroforesterie peut être utilisée pour augmenter la productivité des sols dans les régions semi-arides.

Mots clés : Adoption, changement climatique, sécheresse, faible fertilité, arbres à usages multiples, Zimbabwe

Introduction

The human population in sub-Saharan Africa (SSA) is increasing geometrically, thereby increasing food demand (Canning *et al.,* 2015). The gap between food demand and food production has increased in recent years owing to the increasing global population (Davis *et al*., 2017) and crop harvests for direct food use are insufficient to meet the UN's food security goal (Canning *et al*., 2015). Arable land is limited on the planet, and several anthropic activities, such as urbanization and soil degradation, have led to further reduction of this land. Therefore, improved and sustainable food production systems with high yield per unit area are required. A study by the African Futures Project (FAO, 2014) showed a widening gap between domestic food supply and demand, which has serious consequences for food stability (Nair *et al.,* 2009). Declining and stagnant soil productivity is a perennial challenge among smallholder farmers in sub-Saharan Africa (Dawson *et al*., 2014).

Soil productivity encompasses soil fertility, together with inherent and management-related factors affecting plant growth and development (Zingore *et al*., 2005). Soil productivity is generally measured in terms of inputs and outputs, and generally refers to water and/or nutrient input versus crop yield. Critical soil functions that influence productivity within any soil ecosystem are those that provide physical support, a rooting medium with plant-available water, air for respiration, and essential nutrients. Therefore, soil productivity affects crop productivity, and farmers have a great influence on soil productivity by altering soil properties.

Crop productivity in SSA is low mainly due to inherent infertile soils, low soil moisture content, poor agronomic practices, drought, and pests and diseases (Bharati *et al*., 2002). In Zimbabwe, the largest area (>76.66%) receives low and unreliable rainfall and is covered by shallow, acidic, and infertile soils, making rainfed crop production a challenge. Zimbabwe is classified into five agro-ecological regions based on the amount and reliability of rainfall received. The natural region (NR) V was the driest, and crop production was reduced by low soil moisture (Table 1). Unfortunately, > 70% of the population in Zimbabwe dwell in these dry regions and depend on rain for crop production, suggesting that a proportionally large group of people is vulnerable to food shortages (Zingore *et al*., 2005). Hence, without drastic improvements in crop production, the country relies heavily on food imports.

Most smallholder communal farmers in Zimbabwe lack farming resources such as irrigation infrastructure, synthetic fertilizers, and pesticides, thereby reducing soil productivity, especially in semi-arid regions. Therefore, these farmers rarely apply fertilizers but rely on natural soil fertility for crop production, which further depletes soil status (Dawson et al., 2014). Given that soils are inherently infertile and have low water holding capacity due to low (< 2% organic carbon content) (Parwada *et al*., 2022), crop production in semi-arid areas is a challenge; hence, sustainable innovation is required.

The agriculturally marginalized natural regions (NR) III, IV, and V covered the largest area (76.66%) of Zimbabwe (Table 1). However, a proportionally large population (79.02%) of smallholder farmers is located in these areas (Table 1).

Rainfed crop production usually fails because of soil infertility and low soil moisture NRs III, IV, and V (Zingore *et al*., 2005). However, these marginalized regions probably have an ideal combination of desirability and feasibility for agroforestry (AF). The recommended farming activities for these regions lend themselves well to the possible inclusion of AF. This could be possible if ideotype AF tree species that have a rapid growth rate and high nutritional value for livestock are included in the system. At the same time, the multipurpose tree (MPT) species thus introduced, if carefully selected, could, after the first few years of growth, prove to be harder and more viable than any of the cash crops such as cotton and tobacco currently being produced there (Parwada *et al*., 2022).Semi-arid regions offer the possibility of introducing some agroforestry systems integrated with crop production, especially as these are areas of extremely high (> 32^{o}C °C) temperatures for most of the year. High temperatures are known to have adverse effects on plant growth and evapotranspiration, and therefore, affect the productivity of the soil. Although rainfall is low, it is

Table 1. The natural farming regions of Zimbabwe

Region	Soil type	Average rainfall (mm) per year	Rainy Season	Total area covered (%)	Proportion of smallholder farmers (%)
I	Red clay	>1000	Rain in every month of the year and relatively low temperature	-	-
II	Sandy loams	750-1000	Rainfall is mostly received in summer (October-April)	18.68	10.10
III	Sandy, acidic, low fertile	650-800	Infrequently heavy fall of rainfall. Subjected to severe seasonal droughts and severe mid-season dry spell. Rainfall is confined to summer with relatively high temperature	17.43	15.01
IV	Sandy, acidic	450-650	Rainfall is characterized by frequent seasonal droughts and severe dry spells during the rainfall period. Rainfall is confined to summer (October-April)	33.03	30.41
V	Sandy, acidic and infertile	<450	Very erratic rainfall confined to summer season (October-April). Very high temperatures during the summer	26.2	33.60

Adapted from Parwada *et al.* (2022)

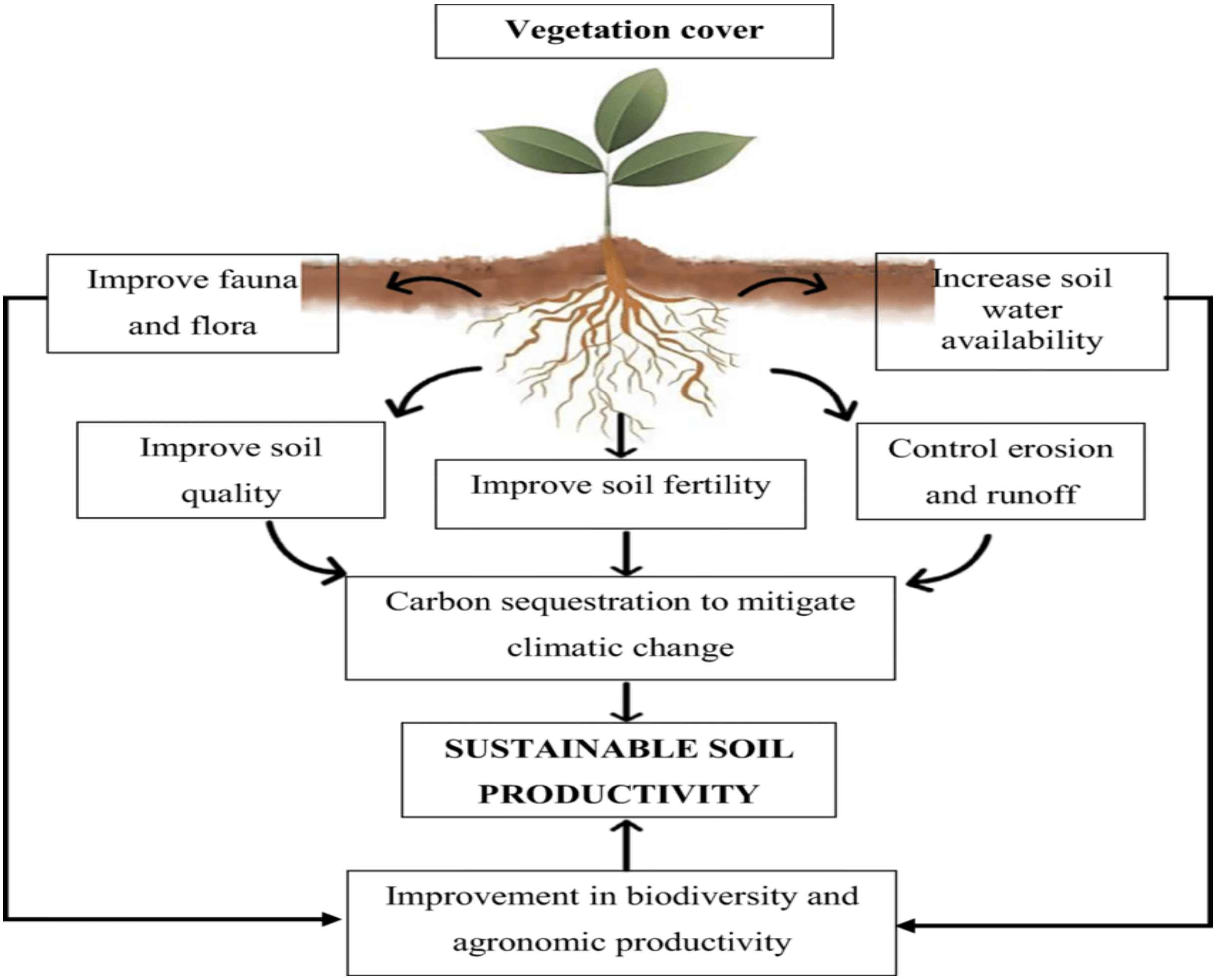

Figure 1. **Use of multi-purpose tree cover for sustainable soil productivity**. *Adapted from Zuazo and Pleguezuelo (2008)*

necessary to ensure an adequate supply of water for the trees only in the first year or second because most of the area covered by natural regions III, IV, and V has extensive reserves of ground water. Trees would then be able to exploit this groundwater better than most other crops (Dawson *et al*., 2014). Over time, changes in vegetation could result in desirable microclimatic effects in these dry regions. Figure 1 shows how trees can be effectively used to enhance soil productivity in the semiarid regions of Zimbabwe.

The semi-arid regions of Zimbabwe receive low rainfall (< 450 mm per year) and hence are dry for most of the growing season (October to April), so low soil moisture recharge leads to crop moisture stress. Low crop biomass productivity results in poor soil health because it reduces soil organic matter content. The summer (October to April) temperature is also very high (>32^{o}C °C), so there is increased evapotranspiration, which compounds the soil dryness problem that lowers crop production to 0% in other areas, such as Matabeleland North. Strategies aimed at reducing the rate of evapotranspiration and increasing water holding capacity and soil fertility are therefore imperative. Considering the perennial decrease in crop yield in semi-arid land (NR IV & V), non-conventional crop production systems, such as agroforestry, can offer solutions to harsh crop production conditions. Agroforestry (AF) is an old practice that, if well implemented, can be a panacea for low soil productivity in the semi-arid areas of Zimbabwe. However, farmers have to adopt AF technology first in order to benefit from it. Despite extensive research on AF, many questions regarding its adoption remain unanswered (Amare and Darr, 2020).

Unfortunately, the uptake of AF practices remains low among smallholder communal farmers in Zimbabwe. This finding suggests the need for innovative ideas to improve our understanding of AF design and management. Therefore, this review examined the following: (1) opportunities for using agroforestry practices to enhance soil productivity in the semi-arid regions of Zimbabwe, and the adoption of agroforestry technologies and practices in the dry areas of Zimbabwe.

Agroforestry as a cropping system. Agroforestry involves intentional inclusion of perennial woody tree species in crop and/or animal production. The aim is to promote positive interactions between the included trees and field crops, thereby promoting ecological productivity, socio-economic benefits, or both (Nair *et al*., 2009). A well-designed agroforestry system can enhance biological activities in an agroecosystem and provide many other benefits, such as non-timber forest products that include honey and mushrooms. Agroforestry provides ecological services at different levels, such as modification of the lateral flows of water and sediment, as well as spatial nesting (Parwada *et al*., 2022). Noting that rainfall is limited in the semi-arid regions of Zimbabwe, modification of the lateral flows of water can be a viable strategy to increase soil water (Botero and Barker, 2002).

Limited soil moisture and low soil nutrient content are the major limiting factors for crop and pasture production in the drier regions of Zimbabwe. However, AF practices can solve these problems because nitrogen-fixing tree species can improve the N content and biomass added to the soil organic matter (SOM). SOM affects various soil properties and processes and engages in multiple reactions, such as soil aggregation and erosion control, availability of plant nutrients, and amelioration of other forms of soil degradation (Parwada and van Tol, 2019). Tree crowns create a microclimate around the crop environment by providing shading, reducing wind speed, and conserving soil moisture, thereby improving crop productivity. In a long-term field experiment under highly unstable Lixisols, AF practices (FAO, 2014) increased soil organic carbon (SOC), mean weight diameter (MWD), and soil water storage (SWS) (Table 1). In the experiments, the soil parameters increased twice as much under AF compared with conventional cropping systems. This confirms that the inclusion of perennial woody tree species in traditional farming fields can improve both the soil physical structure and nutrient holding capacity (Bharati *et al*., 2002).

The maize yield ranged from 0.62-0.8 t ha^{-1} and 1.8 to 3.9 t ha^{-1} under conventional cropping systems and different agroforestry (improved fallows and alley cropping) systems respectively (Table 1). Improved fallows included deliberate planting of fast-growing *Cajanus cajan* (pigeon pea) for rapid replenishment of soil fertility. This was used as a sensible method for in situ accumulation of large quantities of N in the soil, as well as for providing sustainability-enhancing services. In contrast, alley cropping involved planting rows of *Tephrosia vogelii* (tefrosia) that were wide enough to create alley ways within which maize was planted. Generally, AF systems improve soil and crop productivity and guarantee income to farmers in various climatic zones (Franzen and Mulder, 2007). In another study, mulch-cum-manuring with *Gliricidia* was found to increase castor yield by 300% in comparison with no fertilizer applied and 150% in comparison with farm yard manure and use of chemical fertilizer (Srinivasarao *et al*., 2011). The application of Gliricidia leaf manuring has increased the yields of different rainfed crops in many regions, such as finger millet in red (Alfisols) soils.

Table 2. Effects of different agroforestry systems on the soil organic carbon (SOC), mean weight diameter (MWD) and soil water storage (SWS) and maize yield in Lixisols under communal farming system Zimbabwe

Agroforestry system	Soil property and maize yield	Time (years) 1	2	3	4	5	6	$LSD_{0.05(CS\times T)}$
Improved fallows	SOC (%)	0.46	0.82	1.3	1.8	2.1	2.4	0.4
	MWD (mm)	0.32	0.48	0.53	0.63	0.64	0.68	0.08
	SWS (mm)	19.3	25.2	35.5	36.8	37.9	39.1	1.1
	Yield (t/ha)	3.1	3.5	3.4	3.7	3.9	3.9	0.2
Alley cropping	SOC (%)	0.46	0.76	0.89	1.1	1.4	1.5	0.11
	MWD (mm)	0.32	0.41	0.49	0.54	0.60	0.62	0.06
	SWS (mm)	19.3	23.5	27.5	33.2	35.2	36.1	1.3
	Yield (t/ha)	1.8	2.1	2.2	2.5	2.6	2.6	0.3
Rotational woodlots	SOC (%)	0.46	0.79	1.2	1.7	2.0	2.2	0.3
	MWD (mm)	0.32	0.47	0.52	0.61	0.63	0.66	0.08
	SWS (mm)	19.3	24.8	29.8	35.6	36.8	37.2	1.2
	Yield (t/ha)	-	-	-	-	-	-	-
Conventional	SOC (%)	0.46	0.45	0.39	0.38	0.40	0.41	0.3
	MWD (mm)	0.32	0.30	0.31	0.29	0.27	0.26	0.07
	SWS (mm)	19.3	20.1	19.6	19.3	18.4	17.8	1.3
	Yield (t/ha)	0.8	0.75	0.71	0.62	0.72	0.68	0.06

*Conventional= growing annual crops without trees. Source: Data adapted from (Parwada *et al.,* 2019)

Poor crop management practices in conventional systems (low application of fertilizers and sometimes no application) favor high production of greenhouse gases that accelerate climate change. Climate change has already had a negative impact on crop production in the semi-arid regions of Zimbabwe and has rendered traditional planting dates absolute. Both the seasonal quality and length have been negatively altered, causing recurrent crop failure among farmers. By planting trees, high quantities of carbon can be captured, thereby reducing the atmospheric carbon. Therefore, they can negate human-produced carbon emissions and mitigate climate change. In addition, trees at the farm level have ecological benefits that are more essential than the potential agricultural and economic benefits (Nair et al., 2009). These ecological benefits include modification of the farm-ecological structure, biodiversity, and the performance of various ecological systems. The AF mimics natural ecosystems, unlike conventional agricultural practices that clear trees on farmlands.

Role of agroforestry in biodiversity conservation in Zimbabwe. In Zimbabwe, trees have been used in farming systems unconsciously to maintain soil productivity and have favorable effects on crops (Parwada *et al*., 2022). However, traditional fallow periods have been drastically reduced, leading to land degradation and lower agricultural yields. One option that is suitable for avoiding the adverse effects of deforestation and reduced fallow periods is the intentional inclusion of agroforestry into traditional farming systems. Agroforestry is usually aimed at developing a more sustainable form of land use that can improve farm productivity and the welfare of the rural community as a whole.

There is low biodiversity in the semi-arid regions of Zimbabwe because of low soil productivity and little vegetation growth. Therefore, low biodiversity both above the ground and soil biodiversity, as low production of organic matter in the areas, reduces soil microbial activities. It is not questionable whether AF builds higher biological diversity, hence promoting the stability and productivity of an ecosystem (Dawson *et al*., 2014; Canning *et al*., 2015). Nevertheless, the application of conventional agricultural practices such as monocropping and the use of hybrids and pesticides has reduced the biodiversity and functioning of the ecosystem (Parwada *et al*., 2022). Dawson *et al*. (2014) concluded that growing a variety of trees at a farm minimized seasonal variations in the provision of the farm ecosystem.

Agroforestry has great potential for restoring and maintaining soil fertility and increasing crop production in semi-arid areas of Zimbabwe. Perennial woody tree species are essential components of AF systems. The tree reduces nutrient loss from the productive system through efficient nutrient cycling. The addition of nutrients through litter decomposition, dead root biomass, and N_2 fixation increases the importance of tree species in improving the soil nutrient status. The floral diversity of AF systems creates suitable conditions for soil microbes to aid in the decomposition and release of nutrients (Nair et al., 2009). Litter nutrient release depends on the litter composition, soil type, microbial communities, and soil properties. High values of C:N, C:P, lignin, and lignin to N ratios lower the decomposition rate, whereas high nitrogen and phosphorus contents accelerate the decomposition rate (Parwada and van Tol, 2019). This will assist in the selection of agroforestry trees to be included in a system where trees with high-quality litter would be preferred to those with low-quality litter in semi-arid regions. Based on the rate of litter decomposition, the semi-arid soils of Zimbabwe have low rates of litter decomposition, which lower their quality. Crop productivity is also relatively reduced in these soils, unlike in soils from areas with high rainfall. However, there is a need to quantify this through on-farm research.

Trees can release nutrients from their fine root biomass, which is another way to improve soil nutrient health in an agroforestry system. Physiologically, trees are known to allocate a large portion of their gross primary production belowground for the production and maintenance of roots and mycorrhizae (Nair *et al*., 2009). Under such conditions, the soil organic carbon (SOC) content is enhanced, which improves the biological and physicochemical soil properties. Nevertheless, there is little information on the amount of nutrients supplied through the roots in an agroforestry system, especially in dry areas. Generally, the roots of trees are deep and spread, so they are capable of taking up nutrients and water from deeper soil layers, which most annual crop roots cannot reach. This process of drawing up nutrients from lower soil profiles and depositing them on the surface layers through litter fall and other mechanisms is called 'nutrient pumping' by trees. Nutrient pumping is dependent on the characteristics of tree species and other soil, climatic, and topographic factors in an area. Trees adapted to dry conditions have deep root systems that enable nutrient and water pumping as compared to those from high-moisture soils (Zhang and Fu, 2009). The adaptability of trees to low-moisture soils can increase soil productivity by enhancing nutrient pumping in the semiarid regions of Zimbabwe.

Communal farmers in Zimbabwe lack money to purchase chemical fertilizers; therefore, the yield of the annual crop suffers. In addition, overdependence on N fertilizers in intensive crop production decreases its use efficiency and causes environmental problems (Nyamangara et al., 2020). Agroforestry is a sustainable alternative to soil improvement through atmospheric biological nitrogen fixation (BNF), which can play an important role in resolving problems associated with the use of chemical fertilizers among communal farmers in Zimbabwe. BNF occurs through both symbiotic and non-symbiotic means. Dinitrogen (N_2)-fixing trees can be grown in soils with inherently low N content and can replace the N lost during harvest. High N_2-fixation rates, of up to 92 % have been observed in some N_2-fixing trees (Razafintsalama *et al*., 2022).

However, it is important to note that BNF is dependent on physical, environmental, nutritional, and biological factors; therefore, inclusion of an N_2-fixing plant system does not guarantee increased contributions to the soil N pool (Nair *et al*., 2009). Therefore, the BNF fixation rate is site-specific, and the role of agroforestry tree species in increasing soil N must not be generalized. The literature acknowledges that legume trees fix atmospheric N into soils, but there are few studies that are site-specific, especially in the semi-arid regions of Zimbabwe. Therefore, there is a need for research to determine the quantities of fixed atmospheric N by different AF tree species in semi-arid regions. This information will assist in the design of agroforestry systems.

Factors influencing BNF. BNF is influenced by many environmental factors, such as soil moisture, pH, N and P soil content, and soil temperature. The semi-arid areas of Zimbabwe have low moisture content and are acidic, which can be a potential challenge for using leguminous AF tree species to improve soil fertility. Fortunately, there is evidence of the presence of rhizobia in dry soils and the effective nodulation of legumes. This suggests that rhizobia can exist in soils with limited moisture levels, which makes it possible to integrate BNF trees into soil fertility improvement in semi-areas. Dry soil conditions generally reduce rhizobial activity and can be severe if the soil becomes too dry, and an increase in soil moisture is also associated with increased nodulation and rhizobial activity (Razafintsalama *et al*., 2022). This suggests the need for improved tree management, for example, watering of leguminous trees planted in dry regions, if high rates of BNF are to be achieved.

Soil texture was observed to affect the survival of nitrogen-fixingmicrobes.Thesurvival of Bradyrhizobium spp. from Cajanus cajan was reduced in sandy loam soil, such that the strain did not persist in the next cropping season. The survival and activity of microorganisms may depend on their distribution among microhabitats and on changes in soil moisture (Fu *et al*., 2022). High soil temperatures in tropical and subtropical areas are a major problem in the NBF of legume plants (Onwuka and Mang, 2018). If root temperatures are high, bacterial infection and N2 fixation in several legume species are negatively affected. Temperature affects root hair infection, bacteroid differentiation, nodule structure, and the functioning of the legume root nodule, and high soil temperatures delay nodulation or restrict it to the subsurface region (Sharma *et al*., 2020).

The soil pH is another factor that affects the BNF process. Soil acidity is a significant problem in semi-arid regions in Zimbabwe and limits legume productivity (Tauro *et al*., 2011). Many leguminous plants prefer neutral or slightly acidic soils for growth, especially when they depend on symbiotic N_2 fixation (Zahrain, 1999). Ferguson (2013) reported that pasture and grain legumes acidify soil to a greater extent and that legume species differ in their capacity to produce acid. However, legumes and their rhizobia show varied responses to acidity. Some species, such as lucerne (*Medicago sativa*), are extremely sensitive to acidity; however, soil acidity generally constrains symbiotic N_2 fixation in the tropics (Unkovich, 2012). The failure of legumes to nodulate under acidic soil conditions is common, especially in soils with pH < 5.0. Research has indicated the destructive effects of acidic soils on rhizobium-legume symbiosis and N_2 fixation (Olaniran *et al*., 2013). Low pH causes a reduction in the number of *Rhizobium leguminosarum* and can result in no or ineffective nodulation of some plants, such as clover (Ferguson *et al*., 2013). Again, in acidic soils with a pH of .5.0 and heavy-metal activity is relevant, the presence of available aluminum inhibits nodulation (Olaniran *et al*., 2013). Soil salinity and acidity are typically accompanied by mineral toxicity (specific ion toxicity), nutrient deficiency, and nutrient disorders. Salt damage to non-halophytic plants grown in nutrient solutions is often due to ion imbalance (disorder) rather than osmotic potential, which results in poor nodulation (Wang *et al*., 2022).

N-fixation by Frankia-actinorhizal symbiosis is limited by the low availability of P in soils. Research has shown increased N_2 fixation by *Casuarina equisetifolia* when phosphate was added to P-deficient soil, and there was a significant increase in the yield of Frankia-inoculated *Casuarina cunninghamiana* by adding phosphate to the soil (Karthikeyan *et al*., 2013; Ngom *et al*., 2016). Low P status is a frequent limitation to the nodulation of actinorhizal plants. Studies have concluded that symbiotic N_2 fixation of the Frankia-Casuarina association requires higher P levels than those required for plant growth when the P concentration in soil is low (Pawlowski and Bergman, 2007; Karthikeyan *et al*., 2013) hence, soil P concentration greatly affects the BNF.

Potential challenges in the adoption of agroforestry in the semi-arid regions of Zimbabwe. Some of the constraints faced by smallholder farmers in using agroforestry practices include techno-information, cost and public policy constraints, technical support constraints, land, belief and risk-taking constraints, and agricultural extension/planting material constraints. Farmers must be properly given the required attention through extension activities in agroforestry practices that can encourage them to plant agroforestry trees. Establishing model agroforestry farms at the village level can be a productive extension approach; however, successful extension programming requires partners to share both an appreciation of the problem and a vision of successful outcomes. Successful promotion also requires an appropriate choice of message, messenger, target audience, and the effective use of appropriate communication tools.

Tree-based constraints include trees that produce chemicals that inhibit the growth of other plants (allelopathy). Trees such as eucalyptus should not be included in an agroforestry system, as they release highly toxic volatile terpenes that inhibit the germination of other seeds (Zhang and Fu, 2009). Another example is neem, which is commonly used in cosmetics, medicine, and pest control. This tree releases chemicals that affect root growth in common field crops, such as wheat, maize, and soybean. In a study by Demie *et al.* (2022), more than one-quarter of the oat harvest was lost in the presence of neem trees on the field boundary. Currently, the interactions between trees and different crops are not yet fully understood. Some research has to be conducted to determine how to eliminate negative influences and encourage the positive effects of trees on field crops (Karthikeyan *et al.,* 2013). Successful agroforestry systems require proper knowledge and evaluation of the complexities of a multidimensional production system. Farmers should master methods of combining different plant species, considering their compatibility and long-term effects on each other.

Agro forestry (AF) may fail miserably when applied to incorrect situations. Therefore, it is recommended to consult experts on local conditions, market situations, and government regulations for land management. Another constraint to the process of developing the right system for the desired purpose is the long timescale associated with the benefits from agroforestry. Most farmers can harvest trees only once during their lifetime. Farmers also lack experience and knowledge of the best management practices;

hence, many studies are based on trial and error. The lack of information combined with poor understanding of how agroforestry could improve production results in poorer subsistence farmers, who could have benefited from this practice the most, are often reluctant to try (Demmie et al 2022). More research and awareness raising are needed if we want to see more trees on farms. In the semi-arid regions of Zimbabwe, trees can compete with field crops for growth requirements, for example, for water, making soils drier, and exacerbating problems with available water content in soils. This may be a result of high tree densities per unit area that cannot support high vegetation or from planting unsuitable tree species that require higher soil moisture than native species. Similar problems may arise when trees are grown on soils with low nutrient content, which is a potential danger because semi-arid regions have inherently infertile soils.

In cases where tree-crop roots overlap, the trees can compete with crops for available nutrients. To minimize competition, it is recommended to add fertilizer to crops grown closest to the trees and plant deep-rooted trees rather than shallow-rooted varieties with lateral root branching. Despite research on the many benefits of AF for sustainable crop production, supportive policies for agroforestry are still insufficient in Zimbabwe. AF is a unique crop production system that is different from conventional production systems; therefore, policies specifically targeting the functioning of this cropping system are needed in Zimbabwean agriculture. Policies should aim to coordinate and define various elements involved in agroforestry development. There is also a need to simplify regulations to allow smallholder communal farmers easier access to the market.

Conclusion

Zimbabwe has a wide range of macro- and microclimatic conditions, which offer reasonable possibilities for agroforestry. In areas where climatic conditions are optimal, agroforestry faces unfair competition from traditional farming systems, which are considered a more intensive and economical use of land. Some agroforestry systems appear to be possible in low rainfall- high temperature zones. The introduction of agroforestry practices can increase the diversity of agricultural practices and ameliorate the hostility of the environment for other agricultural production systems. Thus, the economic potential of these otherwise inimical environments could increase. There are many prevailing factors that can limit the rate and amount of N fixation in the semi-arid areas of Zimbabwe, such as soil fertility, acidity, and moisture. These factors affect nitrogen-fixing trees differently; hence, there is a need for site-specific research that quantifies the nitrogen fixation rates of trees in semi-arid regions.

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Conflict of interest

The authors declare that they have no conflict of

interest.

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