PLANT SCIENCE TODAY
Vol 12(3): 1-13
https://doi.org/10.14719/pst.8409

eISSN 2348-1900

REVIEW ARTICLE

Cassava intercropping systems for enhanced land productivity and farmer livelihoods: A review

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Received: 20 March 2025; Accepted: 31 May 2025; Available online: Version 1.0: 26 July 2025

Cite this article: Abirami V, Velmurugan M, Thangamani C, Natarajan SK, Davamani V, Indu RC, Venkatachalam SR. Cassava intercropping systems for enhanced land productivity and farmer livelihoods: A review. Plant Science Today. 2025; 12(3): 1-13. https://doi.org/10.14719/pst.8409

Abstract

Cassava is a tropical root vegetable from the Euphorbiaceae family, commonly cultivated for its starchy roots. It serves as a significant source of carbohydrates and calories, especially in Africa, where it contributes to more than 65 % of the global cassava production. Due to its long growth duration, broad spacing requirements and slow early-stage development, this crop presents an opportunity for interplanting with short-duration species, thereby enhancing resource utilisation, land-use efficiency and overall biological productivity. Cassava–based intercropping is widely practised in tropical regions with moderate to high humidity. Intercropping offers several advantages, including enhanced pest control, improved soil health and more effective weed management. Growing cassava alongside short-term crops, such as maize or legumes, can enhance resource utilisation, increase yields and improve the efficiency of land use. The Land Equivalent Ratio (LER) assesses the biological efficiency and economic benefits of intercropping systems about monocultures. cassava-maize intercropping is an extensively utilized and efficient system, as the crops exhibit complementary growth habits and resource needs. Growing cassava with legumes like cowpea, groundnut and soybean can boost soil fertility *via* nitrogen fixation, improve weed management and raise total productivity per land area. Intercropping can also reduce the risks associated with monoculture and offer additional sources of income for small landholders.

Keywords: additional income; cassava; disease and pest control; intercropping; land productivity; soil health; weed management

Introduction

Manihot esculenta Crantz, widely referred to as tapioca or cassava, belongs to the family of Euphorbiaceae and is distinguished by its capacity to flourish in unfavourable soil conditions and its tuberous roots. Both rainfed and irrigated conditions are suitable to cultivate this crop (1). The word cassava is derived from the Arawak Indians' term for the root, "casabi." In Spanish, it is called "yuca"; in French, "manioc"; and in Portuguese, "cassave" and "maniok," respectively. A staple crop in pre-Columbian tropical America, cassava (*Manihot esculenta Crantz)* was widely grown. Soon after realizing its significance, early European traders brought it to Africa in the 16th century (2).

Cassava, grown in one-third of all economically struggling food-deficit countries globally, is a popular staple crop due to its production methods and reliability. Following rice, sugarcane and maize, this is the fourth primary carbohydrate source for people living in the tropics (3). Cassava is a key part of the diets in developing countries and was recognized by the Food and Agriculture Organisation in 2003 as the most important underground vegetable and a significant source of calories in Africa. The New Partnership for Africa's Development adopted the slogan "Cassava: A Powerful Poverty Fighter in Africa" to promote the improvement of cassava varieties and germplasm, aiming to enhance its nutritional value across African nations (4). Cassava is a tropical root that requires at least 8 months of warm weather for its cultivation. In humid climates, it can, however, be damaged by excess water. It conserves water by losing its leaves during dry periods and reviving its growth after the receipt of rainfall (5). Cassava is regarded as a crop that thrives in poor soil and is particularly well–suited to areas prone to drought, where other crops, such as cereals, struggle to survive (6). Cassava has been widely used in tropical Asia and Africa for the production of starch, processed foods, livestock feed and staple foods (7). Nigeria, the Democratic Republic of the Congo, Brazil, Indonesia, Thailand, Angola, Ghana, Mozambique, Vietnam, India and Sierra Leone are the top producers of cassava. The countries with the top production from 2000 to 2023 worldwide are shown in Fig. 1.

Global production of cassava in 2023 accounts for about 333.6 million tonnes (an 88 % rise in comparison to 2000 which is shown in Fig. 2), with more than 65 % of the production being produced in Africa (8), where it is made for domestic consumption by smallholder farmers with an

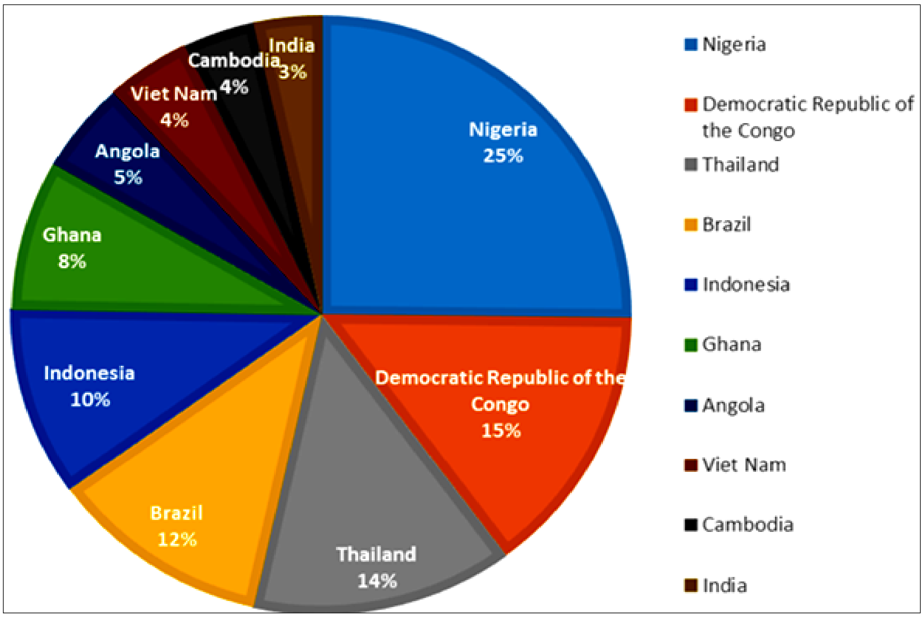

Fig. 1. World leading cassava producing countries (2000-2023) **Source:** (FAOSTAT 2025).

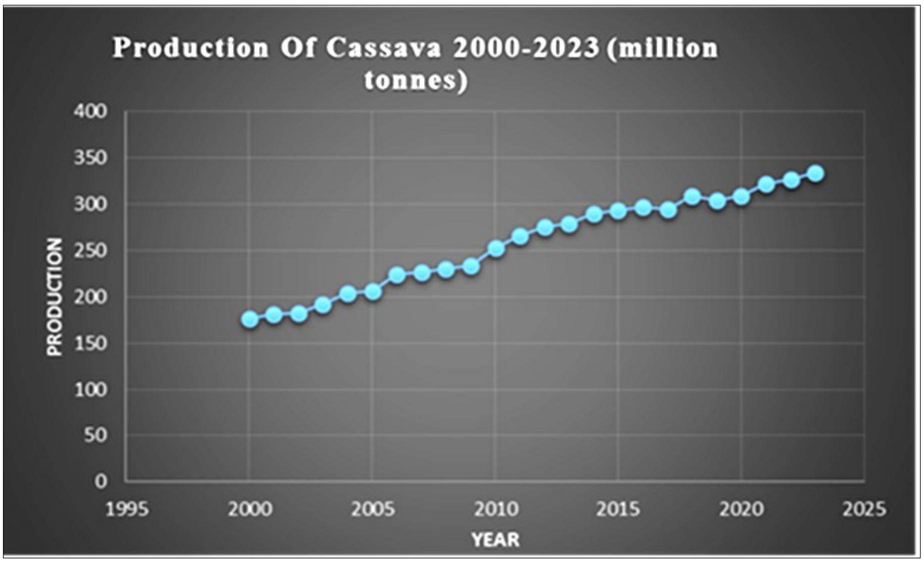

Fig. 2. Rise of cassava production (2000-2023) (**Source:** FAOSTAT 2025).

average grown area of less than one hectare, predominantly in domiciles managed by women (9) with that note cassava in Africa is usually cultivated in intercropping systems alongside other crops like bananas, legumes and maize. With about 61 % of the world's cassava production, Africa is the greatest cassava-producing region (10). India has become a significant player in the world's cassava production, producing 6.94 million tons of cassava with a high yield of 37.90 t ha^{-1} on 0.183 million hectares of land (11). It is cultivated in about 13 of India's 32 states and union territories, with the majority coming from Tamil Nadu and Kerala in the south (142000 and 65700 hectares, respectively) (12). The size of the global cassava processing market was 324.4 million tons in 2024. According to the International Mining and Resources Conference (IMARC) Group, the market is anticipated to grow to 365.8 million tons by 2033, reflecting a Compound Annual Growth Rate of 1.3 % during that period (13). In developing nations, cassava is an "insurance crop" that safeguards rural communities during times of famine and natural disasters. It is furthermore an essential crop for reducing poverty, ensuring food security and promoting climate resilience, particularly for rural and marginal farmers (14).

Significance of intercropping

Intercropping, also known as polyculture, is a classic agricultural technique that involves cultivating more than one crop species in the same field simultaneously during the growing season (15). The objective of intercropping is to establish beneficial biological connections among the crops. In addition to reducing weed, pest and disease pressures and increasing yields, intercropping can also improve biological and economic stability (16). Intercropping is an agricultural practice that offers numerous advantages for sustainable crop production, including risk minimization, increased income and food security, reduced soil erosion, improved pest and disease control and greater financial stability for farmers (17). The primary advantage of intercropping is that it provides greater stability in yield than monocropping (18). The concept of intercropping is well justified, as it has been a widely adopted practice among farmers in tropical regions for many years due to its numerous benefits. These include enhanced ecological adaptability, improved land management and reduced production costs-factors that are particularly important for low -income farmers with limited access to cultivable land (19).

Land Equivalent Ratio (LER) and productivity comparisons

The yield benefits of intercropping can be effectively demonstrated through various methodologies. One such methodology is the Land Equivalent Ratio (LER), a commonly used metric for evaluating the productivity and biological effectiveness of intercropping systems compared to monocropping, relative to each unit of land area. The productivity of intercropping can be quantified using the Land Equivalent Ratio (LER), a widely accepted metric to compare the biological efficiency of intercropping versus monocropping (20). Conversely, an LER of less than 1.0 indicates that the cropping combination is less profitable compared to monocropping. Intercropping provides longer-term ground cover than monocultures, protecting soil from desiccation and erosion (21). Ultimately, intercropping systems optimize output and resource use per unit of land (22).

Intercropping in cassava

Cassava is known for its slow early growth and its capacity to act as a low-soil cover crop. Consequently, cultivating it alongside other crops, such as maize and beans, is very effective, as evidenced by the high harvest index values and Land Equivalent Ratio for cassava and the associated plants (19). Major intercrops followed across the world are given in Table 1 (23). Given that cassava is a widely spaced, long-duration crop, it is possible to plant intercrops in the spaces between its rows, which is advantageous for small and subsistence farmers because it minimizes the risks associated with monoculture and opens up opportunities to earn some quick and additional income (19). Cultivating cassava for many years can lead to a decline in soil fertility and that occurs due to various factors such as (a) plants are spaced far apart, which slows down the development of soil cover during the initial period of growth leads to significant soil erosion; (b) The parts above-ground portions do not return to the soil since the stems are used for planting; (c) there are no root residues left in the soil because the roots are harvested and sold; (d) soil has limited time to recover due to the long growth cycle; and (e) farmers often apply limited amounts of fertilizer (24). Therefore, intercropping, especially a system that includes cassava, has several advantages that make agriculture more resilient and productive. Farmers growing cassava alongside other complementary crops can make better use of available land, achieve healthier soil conditions and experience lower levels of pests and diseases. It also enhances biodiversity while allowing intercropped species to share resources, leading to effective nutrient use (Fig. 3) (23). Intercropping can also be helpful in controlling soil erosion and retaining moisture in the soil, which is crucial under sustainable agricultural conditions in drought-prone areas (25). Cassava cultivation is suitable for planting intercrops since it is a long-duration crop. Similar to numerous other crops, the cassava crop also faces competition from weeds for space, light, water and nutrients (26). Cassava is planted at a 90 × 90 cm spacing and it takes approximately 3 to 3.5 months to produce a sufficient canopy to cover the field completely. During this initial growth phase, planting short-duration intercrops can help maximize the use of solar radiation available between the rows (27). Additionally, intercropping cassava with short-duration crops may lead to the economically viable use of sunlight, water and nutrients available in the spaces between rows (5). Farmers from Thailand, India, Nigeria, Ghana, Brazil and other regions commonly follow a multi-cropping system as a traditional farming practice, where cassava serves as the main crop (28).

Table 1. Major intercrops followed across the world

Countries	Commonly followed intercrops
India	Cowpea, vegetables, coconut, maize
China	sweet potato, peanut, rubber, maize, watermelon
East Timor	Vegetables, banana, maize, peanut,
Cambodia	Maize, cashew nut, rubber, upland rice
Philippines	Maize, peanut, sweet potato
Indonesia	Soybean , cowpea, mung bean, peanut, coconut, upland rice, maize, rubber
Myanmar	Peanut, common bean, maize, banana
Vietnam	Peanut, black bean, rubber, maize, upland rice, cashew nut, coffee, tea
Thailand	Coconut, maize, rubber, cashew nut
Lao PDR	Maize, Job's tear, upland rice, peanut

Source : Cassava agronomy: Intercropping systems (23)

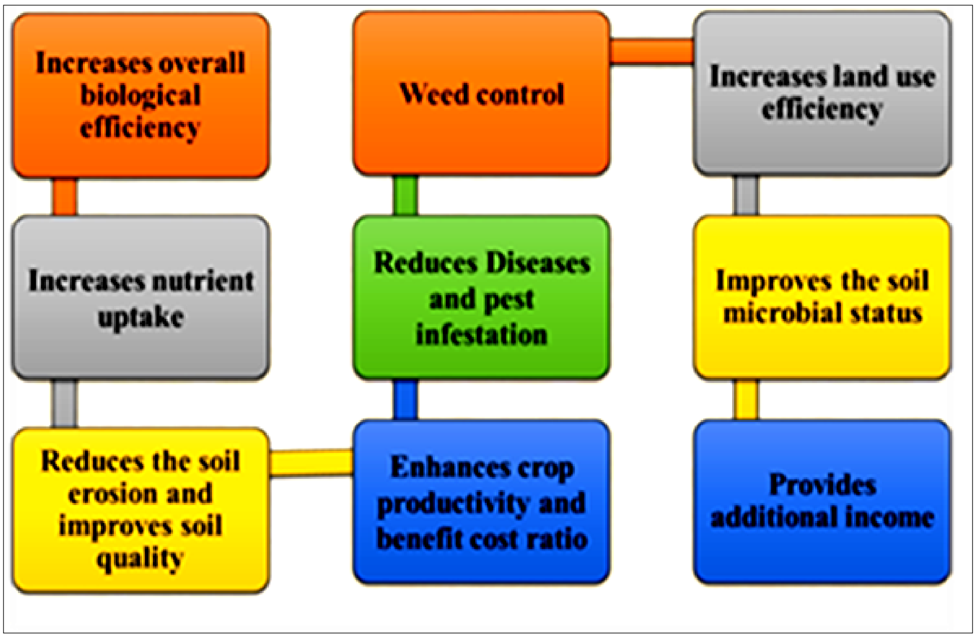

Fig. 3. Benefits of Intercropping.

Hence, cassava is recognised as a crucial crop for enhancing food security in tropical areas, as it is extensively cultivated as a staple food and is well-suited to conditions of low soil fertility commonly found in sustainable farming. Notably, cassava is particularly well-suited for intercropping due to its moderate rate of early growth, making it accessible to self–sustaining farmers who rely on cassava as part of their agricultural practices. Enhancements in the fertility status of the soil, such as improved nutrient cycling and more effective nutrient utilisation, are among the potential advantages of intercropping cassava for enhancing soil health. It also offers additional benefits, including increased soil cover and reduced erosion (29). Grain legumes, especially cowpea, groundnut and soybean, are the integral parts of planting systems. These grain legumes play a critical role in enhancing soil fertility through nitrogen fixation, thereby benefiting subsequent crops. Furthermore, these legumes are the best protein source in human diets and animal feeds; hence, they play a significant role in enhancing food safety and providing a means to produce economic advantages for numerous small–scale farmers (30). Small and subsistence farmers found tapioca to be beneficial since it is a long-term crop that allows for intercropping between rows, lowers the risk of relying too heavily on a single crop and generates quick and supplementary revenue Cassava, a crop that grows slowly in the beginning, uses very little light, nutrients, moisture, etc. during this stage (31).

Role of different intercrops in cassava

Cassava - maize

Intercropping of Cassava and Maize is a widely practised combination in tropical regions (32). The combination of cassava and maize crops complements each other, as their seasons of high resource demand do not coincide (33). Cassava -maize intercropping systems exhibit higher efficiency in land utilisation and greater yield stability compared to sole cropping (34). According to reports, cassava/maize intercrops are quite productive, primarily due to their varied development patterns. (35). Intercropping maize alongside cassava is an exceptionally productive combination in terms of overall production and effective utilization of land; however, the ideal maize density for intercropping with cassava differs depending on the maize variety. Maize that is shorter in height, matures early and has a less dense leaf area which is better suited for intercropping alongside cassava (36). Intercrops that mature early, such as maize or legumes, contribute to weed management, enhance soil fertility, conserve moisture and promote forage production while not harming cassava yield and it also offers extra income (37). Because cassava is a long-duration crop and maize is a short–duration crop, the intercrop of cassava and maize has been acknowledged as both economical and harmonious (38). Compared to cultivating crops like maize and groundnuts separately, researchers have shown that mixing short and long-duration crops improves radiation acquisition and utilization through better timing of canopy formation (39). The practice of growing short-term crops, for instance, maize, in between the growing season of cassava is done since the former crops can be harvested early enough before the cassava canopy closes down during the initial stages of growth and in this way, they can utilize light not absorbed by the cassava (37). Intercropping cassava and maize in a 1:1 row arrangement in Ethiopia can increase land-use efficiency and yield by up to 71 % (40). Intercropping cassava with maize at the plant density of 40000 maize plants per hectare significantly increases productivity compared to other densities. This strategy can improve income and sustain agricultural productivity. These results underscore the inverse relationship between maize density and cassava productivity in intercropping systems. This means that as maize density increases, cassava productivity tends to decrease in intercropping systems. This suggests that high maize density may compete with cassava for resources like sunlight, water, or nutrients, thus reducing cassava yield (41). It also emphasizes the importance of maintaining an optimal plant density (not too dense, not too sparse), along with the right amount of fertilizer supply, to ensure efficient resource use (like sunlight or radiation). Proper management of these factors leads to improved soil moisture retention, which helps plants thrive and ultimately increases crop productivity (42). Cassava and maize intercropping enhanced area equivalency indices and is highly suggested for cassava intercropping (19). Relay intercropping systems, such as maize/cassava and maize/soybean, have been shown to increase soil quality and crop production compared to monocultures. These systems enhance soil nutrient content, particularly nitrogen, phosphorus and potassium (43). Intercropping cassava and maize with specific plant spacing can maximize land use efficiency (44). Cassava-maize intercropping in West Africa reduces pest damage and increases land productivity (45).

Cassava and legumes

Cultivating cassava alongside legumes provides a practical approach to enhancing agricultural productivity, improving food security and promoting sustainable land management. By utilizing the advantages of both crops, farmers can realize higher economic gains while also enhancing the resilience of their agricultural systems (5). Cassava–legume intercropping systems show competitive advantages and higher productivity compared to monocropping (46). Growing cassava with grain legumes allows crop residues to enhance soil fertility post-harvest. However, when crop residues are used as animal feed, the nutrients they contain are not returned to the soil. Therefore, the application of cow manure, which is rich in essential nutrients, becomes crucial for maintaining nutrient balance in intercropping systems (24). Intercropping cassava with legume crops, such as cowpeas, haricot beans, mung beans and soybeans, led to a 49-82 % improvement in land use efficiency (LUE) compared to sole cropping. This validates that the aggregate land equivalent ratio (LER) was more than 1 when legumes were intercropped alongside cassava, signifying that actual productivity surpassed anticipated levels (47). In the cassava-soybean intercropping system, especially with the highest soybean population, the highest productivity and profitability have been achieved compared to sole crop systems (48). When cassava is planted in wide rows with a short-duration crop, it may produce better results than growing each species separately. Before there is much competition between the two plants, the legume attains maturity, providing cassava time to recover from any damage that the legume may have caused (49). Intercropping cowpeas with cassava did not reduce tuber yields and cut wedding costs by 50 %. It also slowed organic matter depletion and improved soil fertility (higher nitrogen, phosphorus and potassium). Moreover, cassava's growth (height, leaves, tuber count, dry matter) was unaffected by the intercrop, making cowpeas a viable and sustainable choice for cassava cultivation in humid tropical regions (50). Cassava intercropping also increased land use efficiency, reaching levels of 42-70 % and had a slight effect on cowpea yield. However, between 20 and 100 % gains in land use efficiency for intercropped cowpea and cassava compared to either crop grown alone were reported (51). A similar conclusion was found in another intercropping study of cowpea and cassava, where land use efficiency increased by 48–56 % (52). Various cassava-centred farming systems have been evaluated and it was found that root yield differed by each system, with the highest recorded yield being cassava-groundnut intercropping (53). Cassava-groundnut intercropping also increases crop productivity, benefit-cost ratio and soil organic carbon compared to monocultures (54). Regarding the land equivalent ratio, intercropping cassava with legumes proved to be beneficial overall (average LER = 1.557), particularly when paired with soybean, cowpea, or peanut (55). Cassava output is increased by intercropping and rotating it with legumes, which is an ecologically sound way to lessen farmers' reliance on outside resources and improve the natural fertility of the soil.

Additionally, intercropping produced a larger net benefit than the legume rotation scheme (56). Studies on cassava-based cropping systems have been undertaken to analyse how soil properties and microbial communities react to soybean intercropping. According to the results, intercropping increases the number of specific advantageous bacterial groups associated with the breakdown of organic matter (57). Plant population is also essential in cassava intercropping systems. After testing four treatments with different populations of cassava and soybean, the one with the highest Land Equivalent Ratio was the soybean treatment of 222222/ha (58). Including legumes in cropping schemes, such as cassava, offers several other benefits. Legumes help increase soil fertility and reduce the need for chemical fertilisers through their nitrogen-fixing power from the air (59, 60). This nitrogen fixation, depending on the legume species, can produce 35-120 kg N/ha^{-1} for future crops (60). Intercropped with legumes like butterfly pea (*Centrosema pubescens*), cassava can raise soil nitrogen levels and organic matter content without much impact on the yield of cassava tubers (61). Legumes also provide protein-rich food alternatives that may help alleviate dietary dependency on cassava (62). Still, the ability to incorporate legumes depends on several key factors, including the choice of suitable types, disease resistance and prevailing environmental conditions (62, 59). To summarise, intercropping systems that integrate cassava and legumes can raise yields, improve soil quality and lead to better nutritional outcomes in small-scale agriculture**.**

Cassava and vegetables

Intercropping cassava with vegetable crops would help sustainable agriculture in several ways. When selecting crops to intercrop with cassava, a short, early-growing cassava variety with a high yield and a high leaf area index (LAI) is advised. It also slows down weed growth and lowers soil temperature as well as raises field moisture, light interception and earthworm activity (63). Cassava is often intercropped with a variety of vegetables, such as sweet potato, yam and other legumes, like groundnut, as well as crops like rice, maize, coffee and coconut. Crops are chosen according to the intake preferences and the surrounding habitat. Simple mixtures have two crops; complex ones have three or more, thereby producing benefits including less weed growth, cooler soil, better moisture retention and less nutrient loss through soil erosion (64). Vegetables are effectively grown in the wide spaces between cassava rows. Cultivating okra as an intercrop in tropical regions with high and moderate humidity can boost pod development and financial gains when planted either two weeks before or at the same time as cassava (65), as proven by various studies. For instance, intercropping okra with cassava has been shown to increase productivity due to their complementarities. This system enables farmers to achieve full cassava yields while generating additional income from okra by maintaining 10000 cassava plants and one-third of optimal okra plants per hectare. This cost-effective system enhances diversification and increases overall yields with minimal investment (66). In comparison to the intercropping of bhendi (okra) alongside cassava and cassava intercropped with pepper, the cassava-pumpkin intercrop resulted in lower soil temperatures, fewer weed dry weights, high moisture content of the soil, more absorbance of light and more castings of earthworm (63).

The other various intercropping studies have also been reported were they discovered that interplanting oilseeds such as Sunflower and Sesame with cassava increases economic efficiency and productivity and also exhibited comparatively high intercrop compatibility as determined by the land equivalent coefficient (LEC) and higher biological efficiency as indicated by the Land Equivalent ratio and Area x Time Equivalent ratio (67). Growing cassava together with *Brachiaria* species (a forage grass) can increase cassava production by up to 2.4 times compared with growing it alone and during the dry season, this procedure of intercropping improves the flavour of cassava tubers. It makes them softer and *Brachiaria* species used in the intercropping technique enhance soil properties, including structure, carbon content and water infiltration, thereby enabling the direct planting of more crops in the *Brachiaria* mulch (68). Similarly, intercropping cassava with Stylo (drought tolerant legume) resulted in positive effects, enhancing both biomass yield of the foliage and fertility of the soil, thereby creating a more environmentally sound farming approach compared to cultivating cassava in a monoculture (69). Cultivating rubber alongside maize and/or cassava offers more comprehensive agronomic benefits than growing each crop in isolation, as shown by Land Equivalent Ratio values exceeding 1. Therefore, in rehabilitated rubber plantations, intercropping cassava and maize can be practised to utilise available land and enhance resource efficiency. However, intercropping rubber directly with these crops has been shown to yield more significant economic benefits, primarily due to improved land-use efficiency, reduced input costs and the generation of multiple income streams during the immature phase of rubber cultivation (70).

Intercropping effect on weed control in cassava

Weeds drastically reduce yields and complicate harvesting in tuber crops, such as cassava. Unmanaged weeds during the crucial stage of crop growth can reduce cassava yield by 50 % to even 100 % (71). Weeds also lower the quality of cassava tubers by using up nutrients meant for roots and tubers or by overtly penetrating underground storage organs (71, 72). Consequently, the management of weeds is highly significant, especially during the time of the initial stages of cassava growth (72). The major weed crops that infest are mostly shade intolerant (Table 2). Hence, shade-intolerant weeds (e.g., *Cyperus rotundus*) can be suppressed by optimizing planting density in intercropping systems (73). Effective weed control results have been obtained in the various intercropping systems of cassava and are presented in Table 3. In cassava-maize intercropping, 37 % of weeds were reduced and adding a dense cover crop to the cassava-maize mixture reduced weeds by 40 % more than when cassava was grown alone (74). In the cassava-peanut intercropping system, intercropping lowered weeds' dry weight and the temperature of the soil while boosting the soil's moisture content, the absorbance of light and earthworm castings (75). Intercropping cassava with legumes like soybean, pigeon pea, groundnut and cowpea improves soil nutrients, reduces weed biomass and increases cassava yield (76). Intercropping with legumes effectively manages weeds and reduces the prevalence of pests and diseases, which is essential for integrated pest management. Legume canopy cover helped suppress weeds and timely weeding mitigated infestations in unweeded fields (77). In the absence of alternative weed management methods, cassava and legumes improved soil surface coverage, which lowered light penetration and thus reduced weed development. In another study, it was claimed that the combination of a cassava-maize intercropping system with long-term leguminous cover crops, for example, *Desmodium heterophyllum* Willd. DC (Spanish clover) leads to inefficient as well as sustainable weed management. (77). Incorporating soybean (*Glycine max* L. Merrill), green gram (*Vigna radiata* L.), maize (*Zea mays* L.), cowpea (*Vigna unguiculata* L.), peanut (*Arachis hypogaea* L.), pigeon pea (*Cajanus cajan* L. Millsp), black gram (*Vigna mungo* L.), common bean (*Phaseolus vulgaris* L.) and melon (*Cucumis melo* L.) as cover crops in intercropping systems with cassava proved to be a productive and promising strategy for controlling weeds in comparison to cultivating cassava as sole crop (37, 33, 71). The spatial arrangement of intercrops plays a crucial role in weed control, with the most effective approach being a single row of cassava accompanied by a double row of legumes (78). Intercropping early-maturing maize and cassava under ideal soil nutrient availability, especially N, may maintain high mixture production and provide good weed control (37). Cassava-groundnut intercropping can function as a weed management technique to mitigate the loss caused by weeds for resource-constrained farmers and can be used as a replacement in the place of chemical weed control and also provides several benefits, including improved soil fertility, weed control, an early nitrogen boost for the following crop and increased yields (79). Intercropping cassava with legumes and cereals effectively suppresses weeds and improves crop productivity. Studies have demonstrated that cassava-legume intercropping systems, particularly with cowpea, groundnut and soybean, significantly reduce weed populations compared to monocrops (80, 78) and integrating legumes into cassava-based intercropping systems could offer a viable method for managing weeds, especially in the place where there are limited resources and cannot be able to invest in herbicides or carry out labour–intensive cultural practices. In addition to enhancing general soil health, this method helps maintain soil fertility and moisture (81).

Table 2. The major weed crops affecting Cassava cultivation

S. No	Major weeds	Family	References
1	*Cyperus Rotundus*	Cyperaceae	73
2	*Tridax procumbens* L.	Asteraceae	
3	*Brachiaria jubata*	Poaceae	
4	*Philanthus amarus*	Euphorbiaceae	
5	*Cynodon dactylon*	Poaceae	112, 113
6	*Imperata cylindrica*	Poaceae	112
7	*Mimosa pudica*	Fabaceae	113
8	*Eleusine indica*	Poaceae	
9	*Chromolena odorata*	Asteraceae	
10	*Amaranthus spinosus*	Amaranthaceae	

Table 3. Effective weed control results from various intercropping system of cassava

S. No	Intercropping combination	Reduction in weed infestation (%)	References
1	Cassava+ Maize	37	114
2	Cassava + Groundnut + Cowpea + Egusi melon	16 to 40	
3	Cassava+ Maize	23.11 *(Cyperus rotundus)*	73
4	Cassava + Bean	47	33
5	Cassava + Okra	40-45	65
6	Cassava + Groundnut	40	26
7	Cassava + Vegetable Cowpea	44.6	
8	Cassava + Blackgram	35.9	
9	Cassava + Pumpkin	44.6	63

Effect of intercropping on soil quality and soil microbial status

Intercropping systems have shown potential for improved nutrient efficiency, enhanced weed control and increased overall biological efficiency (37). In contrast, studies have shown that sole-cropped cassava can lead to reductions in soil organic carbon, aggregate nitrogen, phosphorus availability and potassium ion exchange capacity. In contrast, intercropping cassava with legumes has been shown to improve these soil fertility parameters and significantly increase cassava tuber yield (76) and also observed improvements in the microenvironment, fertility content of the soil and castings of earthworm resulting from cassava–based intercropping techniques (82). Similarly, Intercropping significantly alters microbial community composition, enhancing populations of beneficial bacteria, such as Proteobacteria and Actinobacteria, which are associated with nutrient cycling. Additionally, these systems can reduce pathogenic bacteria and increase microbial diversity (43). Intercropping cassava with peanut improves soil physicochemical properties, increases available nutrients and alters microbial community structures (83). It is an effective land management technique that can enhance yield on smallholder farms and raise soil organic carbon storage, according to the results (54). A study was conducted to investigate the impact of adding soybeans as an intercrop on the soil microbial community in a cassava-based system. The results showed a change in the microbial community, with an increase in beneficial microorganisms, which could enhance soil organic matter (56). Compared to other leguminous crops, growing soybeans alongside cassava indicated improved soil structure as well as less competition (84). Compared to growing cassava alone, intercropping it with Centro (a forage legume) increased the amount of organic matter and nitrogen in the soil (61). Research results showed that planting pumpkins next to cassava improves crop diversity. It also enriches the soil microenvironment, making it an excellent cropping strategy. Intercropping lowered extreme soil temperatures, increased soil moisture content, improved light absorption and boosted earthworm activity, all of which contributed to increased yields (63).

Effect of intercropping on Land Equivalent Ratio (LER)

The success of intercropping compared to monocropping is indicated by the Land Equivalent Ratio (LER). An LER greater than 1 implies a significant increase in productivity. This means that the combined yields of the intercropped system exceed the yields that would be obtained if each crop in a monocropping system on the same area (85), which has been achieved in various intercropping systems (Table 4). Intercropping can lead to a higher land equivalent ratio (LER) even when individual crop yields decline, often due to competition among crops. Integrating grain legumes into cassava systems can improve overall productivity by optimising resource use and enhancing soil fertility (86). Intercropping cassava with legumes usually improves productivity and land use efficiency when contrasted with pure stands. Studies reveal land equivalent ratios (LER) for cassava-legume intercrops greater than 1, indicating increased total yields (47, 84). Cassava–soybean intercropping showed the highest land use efficiency, with yield increases of 76 % for soybeans, 51 % for haricot beans and 15 % for cowpeas over their respective monocultures (84). Another study revealed that cassava intercropped with chickpea and cowpeas enhanced the total land equivalent ratio compared to monocropping (86). Likewise, in comparison with the cassava-chickpea and cassava-Bambara groundnut intercropping systems, the cassava-cowpea intercropping system had a higher Land Equivalent Ratio despite producing the least amount of cassava root yield (87). The combination of cassava and groundnut in intercropping demonstrated a net advantage through efficient space utilisation (LER > 1), resulting in lower operating costs per unit area (88). Compared to intercropping with cowpeas and haricot beans, intercropping along with cassava and soybeans improved land use efficiency by 16.4 % and 19.3 %, respectively. The LER was higher for intercropping than for solitary cropping. Overall land productivity was higher during intercropping than during lone cropping despite lower component crop yields (84). Intercropping combinations such as cassava with upland rice and peanuts yielded LER values of 1.35 and 1.60, respectively, highlighting the benefits of intercropping in agricultural practices (89).

Table 4. Land Equivalent Ratio achieved in various cassava intercropping studies

S.No	Intercropping combination	Land equivalent ratio	References
1	Cassava+ Maize	1.42 – 1.79 1.73 – 2.11 1.16– 1.69 2.51	115 38 116 117
2	Cassava + Legumes	1.55	55
3	Cassava + Cowpea	1.48 – 1.66 1.48 – 1.56	46 52
4	Cassava + Soybean	1.87 2.0 1.92 - 2.14	85 48 46
5	Cassava + Chickpea	1.50	86
6	Cassava + Haricot Bean Cassava + Mung Bean	1.82 1.62	47
7	Cassava + Okra	1.30	66
8	Cassava + Groundnut	2.03 1.58 - 2.07 1.6	88 46 89
9	Cassava + Rice	1.46 - 1.88	118

Effect of intercropping on control of soil erosion

A larger canopy diameter in intercropping systems provides more ground cover, which protects the soil from the direct impact of rainfall, thereby reducing erosion. This is a valuable detail but needs to be connected to erosion control more explicitly (90). Maintaining soil fertility and achieving nutritionally balanced crop outputs were facilitated by cassava intercropped with upland rice and maize, followed by the inclusion of legumes like soybean or peanuts (91). Rotational strategies involving maize also supported long–term sustainability. Cultivating cassava has a considerable effect on soil erosion and fertility in tropical areas. Intercropping systems are more effective at minimising soil erosion than monoculture (92). No-tillage methods paired with intercropping cassava, maize and melon enhance soil fertility, decrease erosion and improve water infiltration (93). The combined shifting and repeated cultivation of cassava with maize results in reduced soil organic matter, nutrient content and pH compared to uncultivated forest soil, with continuous cultivation having a greater impact (94).

Effect of intercropping on light interception

While intercropping cassava with legumes can enhance productivity and soil fertility, its success largely depends on crop compatibility, planting geometry and light interception. Early-maturing soybean cultivars are more suitable for intercropping with cassava, as they allow for better cassava recovery after harvest. Wider row spacing in cassava also allows for more light penetration for intercrop growth. However, intercropped soybeans may suppress cassava growth due to shading or competition for light (49). Interplanting cassava and maize, along with nitrogen fertilization, improves the leaf area index (LAI), enhances light absorption and contributes to better weed suppression (82). The absorbance of light reduces the production of intercrops (38, 95). A cassava canopy may lower the transpiration rates of the intercropped soybean during the dry season, which would aid the plants in retaining the groundwater in the rooting zone, even though it significantly reduces the quantity of light that reaches the soybean (96). On nutrient-depleted soils, the combination of fertilisation, liming and legume intercropping can significantly enhance cassava's radiation-use efficiency, light extinction coefficient and yield potential (97).

Effect of intercropping on the management of disease and pest

Cassava output is significantly diminished because of infestations by pests and diseases (98). Insect pests, alongside declining soil fertility and nutrient deficiencies, significantly hinder legume production. Sole reliance on insecticides poses significant environmental risks and leads to the development of insecticide resistance. Intercropping has emerged as a sustainable alternative for pest management, offering a means to reduce pest pressure while maintaining productivity (46). Cassava intercropping can reduce pest incidence, including whitefly abundance, compared to monocultures and the benefits of intercropping can persist even after the companion crop is harvested, with lower whitefly populations observed for up to 6 months post-harvest (99). Planting cowpea and cassava in alternating rows decreased the disease index's severity by 50 % (100). Studies revealed that intercropping cassava with cowpea and maize reduced the invasion of whiteflies and other arthropod–based insects in Colombia when compared to cassava grown alone (101). Furthermore, the intercropping strategy increases the overall productivity and production per unit of land (17). Research in the Ivory Coast and Benin has shown that CMD was less prevalent in cassava intercropped with cowpea or maize, likely due to reduced whitefly vector activity (102-104). This suggests that traditional intercropping methods standard in Africa may effectively suppress CMD transmission (102-104). Comparatively low numbers of whiteflies seen on cassava interplanted with legumes, in contrast to cassava produced in monoculture, indicate that the presence of legumes in the interplanted areas created unfavourable conditions for whitefly reproduction. Whitefly populations were consistently lower in cassava-legume intercropping systems compared to monocultures. This may be due to repellent or resistance traits in some legumes that create unfavorable conditions for whitefly reproduction (77).

Intercropping cassava with maize presents a viable strategy for managing Cassava Bacterial Blight while also enhancing the economic returns for farmers. By adopting this practice, farmers can achieve better disease management and improve their overall income stability, making it a beneficial approach in cassava production systems. This research underscores the importance of integrated farming practices in enhancing crop resilience and farmer livelihoods (105). Cassava-maize intercropping has also been found to decrease cassava severity of bacterial blight by 53 % (106). Cassava-maize intercropping has also been shown to reduce the severity of Cassava Bacterial Blight by 53 % (106). In addition to lowering whitefly populations, cassava-legume intercropping significantly ($P > 0.05$) decreased CMD incidence and severity (107). Overall, intercropping serves as an effective agroecological strategy for managing major cassava pests and diseases, as evidenced in Table 5.

Effect of intercropping on the economics of cassava

Land Equivalent Ratio (LER) and economic analyses consistently demonstrate the advantages of intercropping over monocropping systems (48, 88). Intercropping reduces production risks while maximizing land use efficiency and economic returns (96). According to reports, intercropping systems can increase land-use efficiency by up to 31 %. This study clearly showed that growing haricot beans with cassava can increase root yields by up to 28 % (108). It has also been shown to reduce soil erosion (109). Compared to monocultures intercropping cassava, maize, soybean and cowpea reduced individual crop yields but resulted in higher overall land use efficiency and stability of the production (34). Intercropping maize with cassava, for example, can increase total yield by 26 % to 71 %, while also supporting pest control and improving soil health (40). Different row configurations in yam-cassava systems can significantly enhance profit margins compared to conventional farming methods (110). Compared to growing either pepper or cassava alone in a single crop system, the total profits from intercropping the two crops were greater (111). Planting cassava alongside legumes may improve production and profitability in different parts of Africa. Research indicates that intercropping cassava and soybean at an entire population of both crops optimizes profitability and overall system efficiency (48). In systems featuring cassava and groundnuts, the use of cassava varieties that have upright branching tendencies results in maximum yield and profit (88). Sowing cassava at the same time or within a fortnight of groundnuts enhances yields and financial benefits in intercropping systems (75). Regional cassava farmers' traditional intercropping methods also reduce the risk of cassava price volatility. There are several agronomic and financial benefits to growing cassava with other crops, such as legumes (108). Overall, cassava intercropping systems offer

Table 5. Major disease and pests controlled through intercropping system

S.No	Intercropping combination	Disease/Pest	Comments	References
1	Cassava + Maize	Cassava Mosaic Virus	Virus incidence reduced	104, 100, 102, 119
		Bacterial blight and Leaf spot	Reduced by 53 % and 81.3 %	106
		Whitefly	65 % Less incidence compared to sole crop	105
2	Cassava + Maize, Bean, Sweet potato	Cassava scab	Lower incidence compared to sole crop	120
3	Cassava + Cowpea + Maize	Whitefly Incidence	Reduced	101
4	Cassava + Soybean	Cassava mite	Lower incidence	46
5	Cassava + Sorghum	Grasshopper	compared to sole crop	121
6	Cassava + Cowpea	Bacterial blight	Lower incidence	122
		Bacterial blight	compared to sole crop	100
7	Cassava + melon	Bacterial blight in cowpea	Lower incidence	123

Table 6. Economical advantage has been supported by various intercropping studies in cassava

S. No	Intercropping combination	Benefit cost ratio	References
1	Cassava+ Maize	1.86	124
2	Cassava + Soybean	1.56	48
3	Cassava + Maize Cassava + vegetables Cassava + Cowpea	1.68 1.62 1.35	125
4	Cassava + Soybean Cassava + Mung bean Cassava + Haricot bean	10.25 8.6 8.7	108
5	Cassava + Groundnut	1.86 2.38	54 26
6	Cassava + Vegetable Cowpea	3.31	26
7	Cassava + Medicinal plants *Plectranthus vettiveroides* *Indigofera tinctoria*	1.91 (Double row) 2.29 (Double row)	126
8	Cassava + Rice	1..39	118

multiple agronomic and economic advantages, as well-documented in various studies (Table 6).

Conclusion

Cassava intercropping is considered both sustainable and efficient, as it helps maximise land use, improve soil quality and increase the farm's overall productivity. Farmers can increase their productivity, reduce competition from weeds and promote biodiversity by cultivating other crops alongside cassava. Moreover, intercropping helps mitigate the impact of pests and diseases and can temper the effects of harsh weather conditions. Properly executed intercropping not only increases profitability but also contributes to environmental sustainability and food security. Therefore, adopting intercropping techniques in cassava farming is beneficial in promoting sustainable agriculture.

Acknowledgements

The authors express sincere and heartfelt gratitude and respect to the Professor and Head, Department of Vegetable Science HC & RI, TNAU Coimbatore and Professor and Head, Tapioca and Castor Research Station, Salem, Yethapur.

Authors' contributions

VA conceptualized the manuscript, performed the literature review and wrote the initial draft. MV collected supporting literature, revised the draft and edited the final version of the manuscript. CT was responsible for organizing and refining the tables. SKN assisted in editing the figures and enhancing their clarity. VD reviewed and formatted both tables and figures for consistency. CIR supervised the manuscript development and provided critical feedback on its structure and content. SRV offered overall guidance and strategic input throughout the preparation of the manuscript. All authors read and approved the final version of the manuscript.

Compliance with ethical standards

Conflict of interest: Authors do not have any conflict of interests to declare.

Ethical issues: None

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