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Intercropping and Nutrient Management in Tuber Crops: A Review

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Authors' contributions

This work was carried out in collaboration among all authors. All authors read and approved the final manuscript.

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Review Article

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ABSTRACT

Among the land used for growing food and tuber crops assume prime importance in human diet after cereals, being a concentrated source of carbohydrates. In Philippines, Java, Indonesia, Sumatra, Malaysia, Bangladesh, India, China and south eastern Asian countries, tuber crops are either the staple or subsidiary food for about one-fifth of the human population. The crop plays a crucial role in satisfying the multifaceted needs of the human population contributing to food, nutritional, social and economic security. In the present scenario of climate change and lack of adequate areas for cultivation tuber crops are gaining a significant importance. Limited availability of additional land for crop production, decreased soil fertility and declining yield for major food

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crops have been cited as the major concerns for agriculture's ability to provide nourishment for the increasing population. The tuber crops are usually long duration crops and it provides a scope for land intensification through intercropping. Intercropping is a farming practice that is commonly adopted in the tropics. Based on the spatial arrangement of crops in the field, intercropping can be largely practiced in various ways. The implementation of intercropping within tuber crop systems, especially in conjugation with leguminous species, has demonstrated considerable advantages in augmenting productivity, pest control and resource efficiency. This methodology not only elevates crop yields but also plays a vital role in promoting sustainable agricultural practices. Another important aspect that affects the overall productivity of the tuber crops is the nutrient management. Nutrient management plays a crucial role in optimizing tuber productivity in the tropical regions. While this review emphasizes the importance of intercropping and tailored nutrient management, challenges remain in ensuring that all farmers adopt these practices effectively, particularly in regions with varying soil conditions and crop requirements.

Keywords: Farming practice; sustainable agricultural practices; tuber productivity; crop requirements soil fertility.

1. INTRODUCTION

Intensive system of agricultural production, where external inputs are often supplied in large quantities there occurs serious negative impact on the soil, water quality and on the biodiversity. In the developing country like India, for fulfilling the food requirement of ever-growing population, there is every need to increase the productivity and land utilization per unit area [1,2]. The best way for the intensification of land is by adopting intercropping [3]. Intercropping is a farming practice that is commonly adopted in the tropics. The choice of component crops and mixture proportions, however, depend on the agroecological zone and the contribution of different crops in the mixtures to farmers' diets and subsistence [1]. Intercropping of tuber crops with crops like pulses offers a myriad of advantages. It boosts system productivity and maximizes land-use efficiency, albeit potentially causing a slight decrease in the yields of individual tuber crops.

Additionally, intercropping enhances soil nutrient levels, suppresses weed growth, and reduces pests and diseases, thereby facilitating the sustainable intensification of crop cultivation. Under the intercropping systems, competition is one of the main factors that is having significant impact on growth rate and yield of plant species [4]. When compared to the monocropping system intercropping possess more efficient utilization of available resources and an increased productivity. As the resource utilization is comparatively greater in the intercropping system there is an increasing interest towards the adoption of intercropping [5]. It is well known that the different species growing together in the same place compete for nutrients, water and light and hence the component crops in the intercropping system should be selected taking into consideration the aspect of competition that exist between different crop components [6]. Apart from the selection of the companion crops the other factors such as relative sowing time [7], spatial arrangement of component crops [8] and fertilizer management [9] plays a key role in the intercropping systems for getting higher productivity.

After cereals and millets, the tuber crops are the third most important food crop in the world. Tropical tuber crops, including cassava, sweet potato, yams (greater yam, white yam and lesser yam) and aroids like elephant foot yam, taro and tannia form the most important staple or subsidiary food to about 500 million global population. In states like Kerala where small and medium sized land holdings forms a larger share the adoption of intercrops during the immature and mature stages is a common practice [10].

The recent hikes in prices of fertilizers have been compelling the Indian farmers to resort to imbalanced nutrition of crops and thus, leading to reduction in crop yields and also causing negative nutrient balance annually [11]. As an alternative way, to overcome the dependence on inorganic fertilizers, usage of organic waste integrated with chemicals and biofertilizers was recommended. Productivity of tropical soils is declining, mainly due to intensive use and depletion of nutrients through harvested crop components without adequate nutrient additions to the soil [12]. In this scenario the integrated application of nutrients has been recommend for reviving the soil fertility and quality. By the integration of bio fertilizers along with N P K fertilizers can save about 25, 50 -75 and 25 per cent respectively of the NPK fertilizers [13]. Another approach is the sole application of organic nutrients to the tuber crops for improving their overall productivity while maintaining and enhancing the soil fertility [14,15]. The organic fertilizers were found to enhance the soil structure and reduce the soil resistance which in turn favors the growth of tuber crops. Various studies conducted in tuber crops such as potato indicated the effectiveness of compost application to reduce the soil resistance whereby increasing the overall growth of tuber crops [16,17]. The application of biofertilizers such as plant growth promoting rhizobacteria (PGPR) increased the nutrient acquisition and also mediated the synthesis of phytohormones [18]. PGPR is well known for its ability to fix nitrogen as well as for its positive effect of the plant growth [19,20] and apart from N the uptake of K and P was also mediated by the interaction with the host plant [21,22].

In this paper, there is a comprehensive compilation of the impact of intercropping and nutrient management on the various aspects pertaining to the tuber crops which includes the growth, yield and quality aspects. Apart from the above listed aspects, impact on other parameters such as soil properties, weed dynamics, intercropping indices and economic feasibility has been discussed underneath.

2. EFFECT OF INTERCROPPING ON TUBER CROPS

As the definition of intercropping says it is the practice which involves the simultaneous growing of two or more crop species in the same piece of land. This could be considered as a comprehensive land intensification method leading to various agronomic benefits. The practice of intercropping within tuber crop systems enhances the growth whereby enhancing the overall productivity, optimizing the land use efficiency and yield supplementary economic benefits when integrated with legumes, cereals and vegetables, concurrently augmenting soil nutrient composition and diminishing the prevalence of pests and diseases [23,24].

2.1 Growth and Growth Attributes of Tuber Crops

In an experiment conducted by Chattopadhyay et al [25], there was significant improvement in the growth and growth attributes of elephant foot yam on intercropping with vegetable cowpea, cucumber and okra. There was a significant increase in the pseudostem girth, height and canopy spread of elephant foot yam when intercropped with vegetable cowpea. Similar findings were observed in the work conducted by Singh et al [5] under intercropping of elephant foot yam. Introducing intercrops and increasing their population led to significant changes in the growth parameters of elephant foot yam. There was a significant increase in the pseudostem height and a decrease in pseudostem girth, canopy spread, and production of leaflets in elephant foot yam [10].

When elephant foot yam was intercropped with garlic or ginger in single/double row planting, [15] opined that the growth attributes were significantly influenced. Elephant foot yam with single row turmeric, resulted in maximum leaf area index (1.88), fresh weight (918.48 g) and dry weight of the plant (107.68 g). [26] opined that when elephant foot yam was intercropped with green gram there was a significant increase in the growth attributes and growth of elephant foot yam. On comparison with the sole crop the elephant foot yam intercropped with green gram has resulted in significantly higher number of pseudostem as well as taller plants.

2.2 Yield Attributes and Yield of Tuber Crops

[12] in his study reported that when elephant foot yam was grown as sole crop the corm yield was found to be maximum (61.27 t ha^{-1}) when grown as sole crop followed by intercropping with cowpea (57.28 t ha^{-1}).

In a field study conducted by [5], where elephant foot yam was intercropped with a variety of vegetables such as bittergourd, ridgegourd and bottlegourd, a significantly higher corm yield was observed in the sole crop of elephant foot yam which was followed by the corm yield obtained in elephant foot yam + bitter gourd. A higher corm length, corm diameter and yield per plant were observed in the sole crop of elephant foot yam, when it was intercropped with ginger and turmeric and it was on a par with the results obtained from elephant foot yam + ginger (1:1). Greater yield attributes have led to a higher corm yield. It was observed that the corm yield in elephant foot yam + ginger intercropping was just 5.5 per cent [10].

Jata et al. [26] observed a greater average corm weight in elephant foot yam when it was intercropped with green gram. Gitari et al. [27] opined that the type of legume that is been used for intercropping greatly influenced the tuber yield of potato. When compared to the sole stand of potato crop, intercropping potato with pea and bean resulted in a significantly yield decrease to the tune of 19 and 16 percentage respectively. There was a significant increase in the average root weight, root numbers as well as root enlargement of cassava by about 39, 33.6 and 27.7 per cent when it was intercropped soybean [1].

2.3 Intercropping Indices

The intercropping indices such as land equivalent ratio (LER) and crop equivalent ratio is being discussed here. The higher values of LER observed in the intercropping systems indicates the superiority of the interspecific interaction or complementarity over the competition resulting in greater land-use efficiency. Indeed, high performance in terms of LER is obtained in plant communities with low competition [28,29].

Among the intercrops such as okra, cucumber, amaranth and cowpea, Chattopadhyay [25] observed that the highest elephant foot yam yield equivalent of about 9.80 t ha^{-1} was obtained on intercropping with cowpea whereas the lowest value of 3.40 t ha^{-1} was from amaranth intercrop. Salau et al. [30] reported that the land equivalent ratio (LER) of cassava+ pumpkin intercropping system irrespective of cassava cultivars, resulted in LER values of 1.42–1.91. There was also a yield advantage of 42–91 per cent when compared with the sole crop of cassava.

In a field study conducted by [10] higher corm equivalent yield of 39.6 t/ha was achieved in the elephant foot yam + ginger (1:2) intercropping system. When compared with the sole crops of elephant foot yam, ginger and turmeric, the increase in corm-equivalent yield under elephant foot yam + ginger (1:2) was in the tune of 10.0, 10.6 and 101.0 per cent. Similarly, the intercropping systems has shown a positive impact on the LER which clearly depicts that the intercropping systems were superior to sole cropping. The maximum LER was noticed in elephant foot yam + ginger (1:2) intercropping which was followed by elephant foot yam + ginger (1:1) and elephant foot yam + turmeric (1:1) intercropping systems.

Jata et al. [26] Observed a higher corm equivalent yield of elephant foot yam under the elephant foot yam + green gram intercropping system on comparison with the sole crop. The increase in corm equivalent yield under intercropping was 13.0 per cent over the sole crop. Lakshmi et al [31], reported that on intercropping ginger and turmeric with elephant foot yam, the LER was greater than one in all the intercropping systems and the range of yield advantage over sole cropping of elephant foot yam was between 33 and 64 per cent. The highest LER of 1.64 was computed in EFY + turmeric system (1:2 row arrangement). Similar trend was observed in corm equivalent yield also.

Benti et al. [1] in his study opined that cassava when intercropped with legumes resulted in land equivalent ratio greater than one clearly depicting the advantageous nature of the intercropping system. As per the results the pure stands required 74, 40 and 46 per cent more land i.e. there was a yield advantage of about 76, 51 and 15 per cent for soybean, haricot bean and cowpea, respectively when intercropped in cassava than pure stand of these crops. In a field study conducted by Gezahegn et al. [2], where cassava was intercropped with legumes LER was greater irrespective of the legume crop. The maximum LER was achieved through the cultivation of cassava in conjunction with cowpea (1.56), with cassava paired with haricot bean (1.54) following closely behind. Conversely, the minimum LER was observed in cassava intercropped with pigeon pea (1.21).

2.4 Quality Attributes and Weed Dynamics

The quality aspects of tuber crops such as starch content, crude protein content oxalate content etc. were greatly influenced by intercropping. Nedunchezhiyan [10] reported that there was significant effect of intercrops on starch and calcium oxalate whereas no effect was observed in the total sugar content. Intercropping of elephant foot yam with ginger and turmeric resulted in higher starch content in corms than the sole crop of elephant foot yam. On comparison with the sole crop a significantly higher amount of starch content was noticed in elephant foot yam + turmeric (1:2) intercropping system.

Weed suppression, the reduction of weed growth by crop interference, has been referred as one determinant of yield advantage of intercropping, being a viable alternative to reduce the reliance of weed management on herbicide use. Recent studies have addressed intercropping as an option for an integrated weed particularly in farming systems with low external inputs management [32].

Płaza et al. [33], in a field study revealed that intercrops reduced the number of weeds in potato crops compared to the control (no intercrops). The lowest values for dry weight and the number of weeds were recorded in the case of potato plantation grown after Persian clover ploughed down in the autumn. Overall, the findings highlight the significance of intercropping as a sustainable weed management practice in potato cultivation, offering a natural and environmentally friendly approach to weed control. [30] opined that cassava + pumpkin had significant impact on weed suppression. The crop combination decreased weed growth by 5-19 per cent and 74-140 per cent when compared with the sole crop pumpkin and cassava, respectively.

2.5 Soil Properties

On integrating legume crops such as lima bean and dolichos bean into potato cropping system, [24] observed that there was significant effect on the soil moisture content as well as the soil temperature. A significant increase of 30 per cent in the soil water content and a decrease in the soil temperature by up to 7.3 °C was seen. Tang et al [34] in a study where cassava was intercropped with groundnut reported an increase in the available N, P, K by nearly 20 folds, and the organic matter increased by almost 40 per cent compared to the control soils and pH value. There was also an increase of about 78.5 per cent in the urease activity under the intercropping system. Cropping of non-nitrogen fixing crops with nitrogen fixing legume crops can improve soil fertility. Benti et al [1], reported that the highest organic matter and total nitrogen was recorded for the sole crop of cassava which was followed by cassava + soyabean cropping system. The pH as well as EC of the soil was significantly influenced by the intercropping. In the study conducted by Tchapga et al [35], an increase in pH, organic carbon and N values were observed in potato + mucuna intercropping systems over the sole crop was observed. On comparison with the initial soil chemical properties, there was an increase of 36.66,11.93, 1.81(%) of N (%), OC (%) and pH respectively after the cropping period.

2.6 Economics of Cultivation

Chattopadhyay et al. [25], opined that the highest net returns and the income per rupee investment were realized from elephant foot yam + cowpea intercropping which was followed by EFY as sole crop. However, the lowest net return was computed from elephant foot yam + cucumber intercropping system.

Nedunchezhiyan [10], observed highest gross returns net returns and benefit: cost ratio on intercropping elephant foot yam with ginger (1:2 ratio). Gitari [23] documented that the intercropping system yielding the highest profit was the combination of potato and dolichos, demonstrating a net income of US$ 9174 per hectare and a benefit-cost ratio of 5.7. This system surpassed the sole potato cultivation in terms of profitability. Jata et al. [26], in his work observed that green gram could be grown as a remunerative intercrop in elephant foot yam. The results revealed that there was an increase of about 16.9 per cent in the net returns on intercropping with green gram on comparison with the sole crop. Elephant foot yam + green gram combination also resulted in significantly higher B: C ratio of 1.8. The field study conducted by Lakshmi et al. [31] revealed the potential of turmeric as an effective intercrop for EFY. On comparison with the sole crop, EFY + turmeric in 1:1 row arrangement resulted in highest benefit cost ratio of 1.90 followed by EFY + turmeric in 1:2 row arrangement (1.81).

3. EFFECT OF NUTRIENT MANAGEMENT ON TUBER CROPS

Nutrient management in tuber crops, like cassava and yams, is crucial for optimal growth. Research shows high response of the tuber crops to manures and fertilizers, emphasizing the importance of proper nutrient supply. Fertilization methods in tuber crops such as cassava, elephant foot yam, potato etc. are crucial in optimizing the growth and yield of the tuber crops. Various approaches have been explored, emphasizing the combination of organic and inorganic fertilizers to enhance the crop growth and its overall performance. The various approaches include the use of organic and biofertilizers, the incorporation of enhanced efficiency fertilizers and adoption of structured fertilization techniques. Although these methodologies exhibit potential, their efficiency may fluctuate contingent upon regional circumstances and particular crop cultivars, indicating an imperative for customized fertilization approaches.

3.1 Growth and Growth Attributes of Tuber Crops

In a study conducted by Bairagi et al. [36], in eastern Uttar Pradesh, incorporation of organic sources of nutrients, such as FYM and vermicompost, along with inorganic fertilizers proved its potentiality in significantly improving the growth and growth attributes of EFY. A maximum canopy spread of 77.00 cm was observed when EFY was treated with 150:60:120 kg NPK ha^{-1} + 50 kg N substituted through FYM indicating better plant growth and development. The organic production strategy for EFY standardized by Suja et al. [37] revealed that a green biomass of 20-25 t ha^{-1} could be realized by the application of FYM @ 36 t ha^{-1} [cowdung + neem-cake mixture in (10:1) inoculated with *Trichoderma harzianum*] along with cowpea as green manure.

Venkatesan et al. [38] Reported that in EFY significantly taller plants (65.27cm) were observed in 100 % RDF (as inorganic) 80:40:100 kg NPK ha^{-1}, followed by the application of 75% RDF (as inorganic) + 25% RDF (as organic) + PSB @ 5 kg ha^{-1} + Azospirillum 5 kg ha^{-1} (57.15cm). A similar trend was observed in case of EFY canopy spread. Significant variation in pseudostem height and diameter, canopy expansion, and the quantity of leaflets per individual plant was observed by Sahoo et al. [39] at 3rd and 5th months after planting (MAP) in relation to the various level of nutrient application. The treatment combination of FYM @10t ha^{-1}, combined with N: P_2O_5:K_2O at 100:60:100 kg ha^{-1}, $MgSO_4$ @ 20 kg ha^{-1}, $ZnSO_4$ @ 10 kg ha^{-1}, and Borax @ 10 kg ha^{-1} yielded an increase in pseudostem height, enhanced pseudostem diameter, greater canopy spread, and an increased number of leaves per plant at both the 3rd and 5th MAP.

Among the different treatments, Kamalkumaran et al. [40] application of nutrients based on soil test results recorded significantly taller plants with a greater pseudostem girth, and number of leaves over control. The INM treatment in cassava (FYM @25 t ha^{-1}+ 100% RDF + cassava booster spray) established higher values of LAI during the initial growth phases compared to other treatments. Similar trend was observed in the crop growth rate of cassava plants [41]. Ghosh et al. [42] revealed that when potato plants were treated with nutrients in an integrated manner *i.e*. vermicompost + urea + FYM + neem cake, consistently exhibited the highest plant weight (23.633 cm) at different growth stages (30 DAS, 60 DAS, 90 DAS), indicating a positive effect on plant growth.

3.2 Yield Attributes and Yield of Tuber Crops

Saraswathi et al. [43], opined that the application of recommended dose of fertilizers as inorganic source realized highest tuber yield in elephant foot yam for two seasons and it was on par with the results obtained by the application of 75 per cent of nutrients through inorganic source and 25 per cent of nutrients through organic sources. The results were in line with those recorded by Saravaiya et al. [44].

The effectiveness of integrated nutrient management on the yield of elephant foot yam was demonstrated by Bairagi and Singh [36], where the application of 50:60:120 kg NPK ha^{-1} + 50 kg N substituted through FYM resulted in significantly superior corm weight per plant (2.64 kg) and total corm yield per hectare (44.24 q ha^{-1}). In an experiment conducted by Sahoo et al. [45] there was significant difference in the corm diameter was observed as a result of different levels of organic and inorganic fertilizer levels. The results revealed that the application of FYM @ 10 t ha^{-1} + NPK @ 100:60:100 kg ha^{-1} in highest corm diameter and it was on par with the application FYM @ 25 t ha^{-1}+ NPK @ 80:60:80 kg ha^{-1}. Venkatesan et al. [38], in the field study reported that the application of 75% RDF (as inorganic) + 25% RDF (as organic) + PSB @ 5 kg ha^{-1} + Azospirillum 5 kg ha^{-1} resulted in significantly superior corm yield (53.47 tonnes ha^{-1}).

Vellayani Hraswa when treated with combination of poultry manure @ 2.5 t ha^{-1} + cowpea (green manuring in situ) + 75: 25: 100 kg NPK ha^{-1} resulted in higher tuber yield of in lowlands [46]. Laoken et al. [47] reported that the combined application of chemical fertilizers along with PGPR resulted in maximum of single storage root fresh weight and storage root yield of cassava. The chemical fertilizer recommendation (CFR) + PGPR gave higher storage root yield by 14 per cent when compared with the sole application CFR.

Gokul et al. [48] Reported that a positive correlation existed between the application of nutrients (inorganic and organic inputs) and the yield attributes. The results of the study revealed that maximum values for yield parameters were recorded when nutrients were given as vermicompost 5 t ha^{-1} + 100 % RDF (80:40:100 kg NPK ha^{-1}) + consortium biofertilizers 5 kg ha^{-1}, followed by vermicompost 5 t ha^{-1} + 100 % RDF (80:40:100 Kg NPK ha^{-1}) and the least values were recorded in control.

The importance of INM in tuber bulking of cassava was depicted by Aravind et al. [41] where the application of FYM @25 t ha^{-1}+ 100% RDF + cassava booster spray has recorded significantly higher tuber bulking rate (TBR) throughout all phases of crop growth. A similar trend was observed in the mean tuber bulking rate also.

3.3 Quality Attributes of Tuber Crops

In a study conducted by Murthy et al [49], maximum starch and protein contents of the corms were observed at when EFY was treated with a relatively higher dose higher N and K doses. Venkatesan et al. [38] reported that the oxalic acid content of EFY was observed to be the highest (102.49 mg/100 g) in 100% RDF (80:40:100 kg NPK ha^{-1}) was given as inorganic form which was followed by 50% RDF (as inorganic) + 25% RDF (as organic) + AMF @ 5 kg ha^{-1} + Azospirillum @ 5 kg ha^{-1} (96.30 mg/100g).

The crude protein content, starch content and carotenoid content of cassava were greatly influenced by potassium fertigation. The results revealed that the above-mentioned quality parameters were remarkably higher in those cassava plants which were subjected to 100 per cent irrigation along with potassium application @ 16mM [50].

Laoken et al. [47] reported the effective of combining chemical fertilizers along with microbial inoculum such as PGPR improved the quality parameters of tuber crops. On application of nutrients as 80 % complete fertilizer recommendation + PGPR resulted in higher starch content of tubers in cassava. The integrated nutrient management showed significant influence on the quality attributes of EFY [48,51], opined that the application of vermicompost 5 t ha^{-1} + 100 % RDF (80:40:100 kg NPK ha^{-1}) + CBF 5 kg ha^{-1} resulted in maximum values for quality parameters of EFY.

4. CONCLUSION

This review emphasizes the importance of intercropping and tailored nutrient management, challenges remain in ensuring that all farmers adopt these practices effectively, particularly in regions with varying soil conditions and crop requirements.

DISCLAIMER (ARTIFICIAL INTELLIGENCE)

Author(s) hereby declare that NO generative AI technologies such as Large Language Models (ChatGPT, COPILOT, etc) and text-to-image generators have been used during writing or editing of this manuscript.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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