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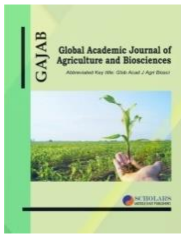

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**Review Article**

# Intercropping System: Enhancing Productivity and Sustainability in Hot Pepper (*Capsicum annum* L.) and Basil (*Ocimum basilicum* L.) Cultivation: A Review


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**Abstract:** The practice of intercropping hot peppers and basil has yielded several benefits, as discussed in this article. Intercropping is the cultivation of multiple crop species in the same plot of land for a specific period with the aim of increasing yield by utilizing resources such as solar radiation, water, and mineral nutrients more effectively. Studies have shown that Intercropping systems capture and utilize more water, nitrogen, and light than single-crop systems, leading to improved moisture and nutrient use efficiency. Additionally, the use of intercropping systems has been found to enhance crop diversification, thereby reducing the risk of total crop failure and improving yield stability over seasons. This practice has also been shown to increase gross returns per unit area, leading to increased land productivity and financial benefits. Furthermore, planting basil alongside hot peppers has been documented to enhance the productivity of the main crop, while reducing losses due to pests, diseases, and weeds caused by the presence of phytonutrients. Overall, intercropping has been found to be an important agricultural activity that allows for increased yield gains through efficient utilization of growth resources, making it an ideal option for the sustainable intensification of crop production.



**Keywords**: Cropping system, Intercropping, LER, MAI.




## 1. INTRODUCTION

Improving agricultural output and efficiency to sustainably feed the continuously growing global population is undoubtedly a significant challenge. This objective can be achieved through the implementation of intensified production systems, which involve the intercropping of different companion crops to optimize the utilization of vital resources such as solar radiation, water, and mineral nutrients. Furthermore, maintaining productivity per unit area of cultivated land is crucial for achieving this goal.

The primary purpose of practicing intercropping systems in crop production is to enhance yield by effectively harnessing resources such as solar radiation, water, and mineral nutrients, which have not been fully utilized in single-crop cultivation within the same land area (Brooker *et al.*, 2015; Temesgen *et al.*, 2015; Sabbagh and Lakzayi, 2016). Intercropping systems have the ability to capture and utilize greater amounts of water, nitrogen, and light than single crops (Temesgen *et al.*, 2015). Exposure of growing plants to light (canopy orientation and branching habits) is the most crucial factor influencing plant growth and crop productivity in intercropping systems. Additionally, intercropping enhances the efficiency of moisture and nutrient utilization compared with single cropping systems. The most significant advantages of intercropping over sole cropping include increased land productivity and reduced risk of total crop failure through improved crop diversification, which leads to enhanced yield stability across seasons and increased overall returns per unit area. Intercropping involves the cultivation of crops with different life cycles, such as annual plants with annuals, annual plants with perennials, and perennial plants with perennials, and is a widely practiced technique based on crop compatibility (Kahn, 2010).

Economic benefits have been observed in the cultivation of hot peppers alongside various species, including fruits, vegetables, forage, aromatics, and medicinal plants such as basil (Kahn, 2010). Furthermore, it has been documented that planting basil alongside hot peppers can enhance the productivity of the primary crop while reducing losses caused by pests, diseases, and weeds owing to the presence of phytonutrients (glucosinolates, capsaicin, and sulfides) (Coolman and Hoyt, 1993; Parker *et al*., 2013; Mutisya *et al*., 2016). Intercropping contributes to the overall well-being of component crops, resulting in the highest yield of hot peppers per unit area of land (Pereira *et al*., 2015). Thus, intercropping represents a significant agricultural practice that enables increased yield gains through efficient utilization of growth resources (solar radiation, water, and nutrients) without the need for additional inputs, making it an ideal option for sustainable intensification of crop production (Brooker *et al*., 2015). Therefore, this study aimed to explore intercropping systems to enhance yield and promote sustainable crop production, specifically by investigating the intercropping of hot pepper and basil and its impact on yield enhancement in the context of sustainable agriculture.

## 2. CROPPING SYSTEMS IN AGRICULTURAL CROP PRODUCTIONS

The origins of crop production can be traced back to the time when early humans transitioned from hunting and gathering, to cultivating crops and raising livestock. As population continues to grow, the importance of food has become increasingly significant, leading to gradual advancements in crop production. The global population has steadily risen from seven billion in 2011 to 9.3 billion in 2050 (FAO, 2017), necessitating a proportional increase in the food supply. However, higher population density has exerted pressure on agricultural land to enhance crop productivity per unit area, time, and resources. Moreover, crop production encounters challenges such as unpredictable weather patterns, water scarcity, and the limited availability of arable land (Kozai *et al*., 2015). Consequently, it is anticipated that 90% of the growth in global crop production will be derived from higher yields and increased cropping intensity, whereas the remaining 10% is attributed to the expansion of productive land (FAO, 2009). Hence, recent trends in agricultural production systems have shifted towards achieving high productivity and promoting long-term sustainability to meet the demands of the expanding population (Aasim *et al*., 2008).

Crop cultivation has been an integral aspect of human civilization since time immemorial. Throughout history, farmers have devised various techniques to optimize crop productivity and ensure sustainability. These methods include crop rotation, relay cropping, and intercropping, in which major crops are planted alongside companion plants. To attain optimal crop productivity, it is imperative to effectively utilize available resources such as solar radiation, water, and nutrients by adapting cropping systems to a specific unit area. Cropping systems involve the cultivation of different crops within a designated area over a defined period. Depending on cropping season, crop type, available resources, and technological advancements, cropping systems can be classified into three categories: crop rotation, monocropping, and mixing/intercropping. Crop rotation involves sequential planting of diverse crops within the same area over multiple years to preserve soil nutrients, minimize soil erosion, and prevent plant diseases and pests. This method replenishes depleted soil nutrients and is believed to hinder the annual development of diseases and insect pests on the same land (Ali, 2003). Conversely, monocropping, which entails the annual cultivation of a single crop on a specific plot, may facilitate the proliferation of diseases and insect pests over time. However, mixed or intercropping systems involve simultaneous cultivation of two or three crops on the same plot of land, utilizing high inputs without compromising the fundamental fertility of the soil. Consequently, multi-cropping is often more stable than monocropping, particularly when resources such as fertilizers, pest and disease control measures, and irrigation are limited or unavailable.

### *2.1 Crop production by intercropping systems*

Intercropping, also known as mixed cropping, is an agricultural practice in which two or more crop species are grown simultaneously on a single plot of land for a specific duration (Brooker *et al*., 2015). This technique is widely employed by small-scale farmers to intensify their farming activities, both in terms of time and space, and is characterized by a low input-low output approach (Sabbagh and Lakzayi, 2016). The coexistence of diverse plant species in intercropping systems is often facilitated by physical modifications of the plant structure or manipulation of the surrounding environment (Coolman and Hoyt, 1993). Mutualism, which forms the foundation of plant interactions in agricultural systems, can be effectively implemented through intercropping (Innis, 1997). Intercropping entails growing crops with different life cycles such as annual plants with annuals, annual plants with perennials, and perennial plants with perennials (Kahn, 2010). Crops cultivated in intercropping systems are typically not sown simultaneously but rather grow in parallel for a significant portion of their life cycle (Singh *et al*., 2013). This method of crop production offers numerous advantages, including crop diversification and sustainable production, by efficiently utilizing available resources to optimize crop productivity (Alabi *et al.,* 2014).

***2.1.1Crop efficiencies for resources utilization in intercropping system***

The benefits of cultivating companion crops in the same unit area have been widely acknowledged. This approach has the potential to augment the availability of vital nutrients for plants, facilitate the acquisition of limited resources, and enhance the management of interactions between the roots and rhizosphere. All of these factors contribute to increased efficiency in the utilization of resources by crops (Brooker *et al.,* 2015). Intercropping systems can capture and utilize greater amounts of water, nitrogen, and light than single-crop systems (Temesgen *et al*., 2015). The efficient utilization of these resources, including light, water, nutrients, and temperature, among the principal crops presents a significant advantage over a single cropping system (Singh *et al.,* 2013). Photosynthetically Active Radiation (PAR) plays a pivotal role in determining the growth and yield of a component crop when other growth resources are not limited (Mahapatra, 2011). Therefore, increased interception of solar radiation, higher light-use efficiency, or a combination of both can lead to improved crop productivity (Najafi and Keshtehgar, 2014). To achieve maximum yield, it is essential for the crop to fully intercept incoming solar radiation, efficiently utilize it within the canopy, and develop the canopy when the radiation levels are at their peak (Singh *et al*., 2013). Ensuring adequate moisture is crucial for determining crop productivity. Intercropping can enhance water-use efficiency in areas where water resources are limited (Brooker *et al*., 2015). Previous studies have indicated that intercropped systems exhibit slightly higher water use and water-use efficiency than monocultures do (Temesgen *et al*., 2015).

Furthermore, intercropping legume crops can reduce input costs by fixing atmospheric nitrogen in a form that can be used by plants, thus improving soil fertility in areas with poor soil quality. Additionally, component crops in intercropping systems can exploit different soil layers, resulting in a larger volume of soil being utilized through the deep rooting of crops that are not absorbed by shallow rooting components (Brooker *et al*., 2015). Therefore, intercropping has mutual and synergistic effects that diminish the risk of complete crop failure owing to crop diversification; enhance yield stability across seasons; provide better control of weeds, pests, and diseases; and prevent soil erosion (Brooker *et al*., 2015). Intercropping is a widespread agricultural practice, particularly in developing countries such as India, China, Nigeria, and Ethiopia, with the aim of enhancing crop productivity (Wang *et al.,* 2014). The productivity of crops in this system depends on various factors, including the type of variety used, planting density, planting arrangement, cropping seasons, and agricultural practices, such as irrigation and fertilization (Bantie *et al*., 2014).

***2.1.2 Types of intercropping***

Intercropping systems have been classified on the basis of the characteristics of the crops involved, such as their spatial distribution and cropping goals (Singh *et al.,* 2013). There are three main types of intercropping system.

1. **Row intercropping:** This type of intercropping is a system in which at least one crop is planted in rows.
2. **Mixed intercropping:** This type also does not have a distinct row arrangement and
3. **Strip intercropping:** Involves growing two or more crops simultaneously in different stripes. The intercropping system can be arranged in several ways.

   i. ***Parallel intercropping system***: This type of strip intercropping involves the cultivation of two crops with different growth habits, but no competitiveness.

   ii. **Companion-cropping system**: This system involves the production of both crops, which is equivalent to the production of individual crops grown separately.

   In both instances, the growth of the two crops was not significantly affected compared with their individual growth (Singh *et al.,* 2013).

   iii. **Multi-storied/multi-tier cropping system:** This involves simultaneous cultivation of two or more crops of varying heights on the same piece of land during a specific period. The aim of this system is to optimize the utilization of production components, such as soil water, air, space, radiation, and other inputs, in a sustainable manner.

   iv. **Synergetic cropping system:** This is characterized by the yield of one crop having a synergistic effect on the second crop. Consequently, the combined yield of both crops is higher than that of a single crop per unit area. This system comprises two components.

a. **Additive series intercropping system**; In this the plant population of the base/main crop within the intercropping system is the same; and
b. **Replacement series intercropping system**: The plant populations of both component crops are lower than the recommended population in a pure stand (Singh *et al.,* 2013).

***2.1.3 Indices of Intercropping***

Different studies have reported that intercropping systems have a yield advantage over monoculture under various agro-climatic conditions (Singh *et al*., 2013). This approach has gained increasing significance in dryland agriculture, as it can help mitigate the risk of complete crop failure by diversifying crop production (Wang *et al*., 2014). Moreover, intercropping allows for optimal utilization of the space between the two primary crop rows by effectively utilizing available resources to stabilize yields throughout the season (Bantie, 2015). Additionally, intercropping offers advantages such as improved weed, pest, and disease control, as well as prevention of soil erosion, which can result in higher gross returns per unit area compared to monoculture systems (Hiebsch and McCollum, 1987; Wang *et al*., 2014). However, the assessment of intercropping performance in relation to sole cropping is incomplete if at least one index is not used in the analysis (Innis, 1997; Yahuza, 2011). Therefore, several indices have been introduced to estimate the intercrop efficiency (Wang *et al.,* 2014). The commonly used indices in intercropping systems are the land equivalent ratio and monetary advantage index.

***2.1.3.1 Land Equivalent Ratio (LER)***

The Land Equivalent Ratio (LER), which is the most widely used index in intercropping systems, determines the yield advantages over sole cropping (Wang *et al.,* 2014). Therefore, LER measures the land productivity of component crops and determines the biological efficacy and productivity of intercropping compared to a single cropping system (Hiebsch and McCollum, 1987; Brintha and Seran, 2009; Amanullah *et al*., 2016). It is expressed as the ratio of land required for a single crop to produce the same yield as that in an intercropping system (Onwueme & Sinha, 1991). According to Willey (1979), the LER value is calculated as

$$\text{LER} = \frac{\text{Yield of intercropping for Crop 1}}{\text{Yield of solecropping for Crop 1}} + \frac{\text{Yield of intercropping for Crop 2}}{\text{Yield of sole cropping for Crop 2}}$$

The results obtained from LER were used to determine whether intercropping was more productive than a single crop. When the value of LER is greater than one (> 1), the overall biological advantage of the intercropping system is greater than that of the sole cropping system (Singh *et al*., 2013). Therefore, the value of one (1) is the critical point at which the intercropping system is favored, whereas a value below one (1) favors sole cropping (Yahuza, 2011).

***2.1.3.2 Monetary Advantage Index (MAI)***

Intercropping offers several agronomic benefits, but does not necessarily guarantee economic advantages. To determine the economic returns from intercropping, it is necessary to evaluate the Monetary Advantage Index (MAI), which computes the returns gained from different crop components in a single cropping system. MAI provides an indication of the profitability of the cropping system, with the highest positive value indicating the maximum profitability of the intercropping system. The Monetary Advantage Index (MAI) is calculated according to Ghosh (2004).

$$\text{MAI} = \text{Value of Combined Intercrops} + \frac{(\text{LER} - 1)}{\text{LER}}$$

The value of the combined intercrops (values of crop 1 + value of crop 2) in each system was determined using the lowest prevailing market price of each component crop per kg at the time of the harvest.

***2.2 Yield advantage and economic return from intercropping system***

Many scientific studies have consistently documented the benefits of intercropping in terms of yield and economic advantages compared with cropping systems alone. However, several factors, such as the selection of cultivars, seeding ratio, planting pattern, and competition between component crops, can influence the growth of species in intercropping systems (Aasim *et al*., 2008). Most studies on intercropping have primarily focused on cereal-legume intercropping, and numerous scholars have globally reported the yield and economic benefits of this system. For instance, Kebebew *et al*., (2014) observed a yield advantage of 32% for maize when intercropped with soybeans compared with sole cropping. Nigussie (2015) also reported a 40% yield advantage for maize when intercropped with haricot beans compared to a single cropping system. These advantages can be attributed to the efficient utilization of nutrients by both crops and enhanced nitrogen capture by haricot beans, thereby improving the performance of companion crops (Temesgen *et al*., 2015). Similar to the reported yield and economic benefits of intercropping cereals with legumes, the intercropping of medicinal and aromatic plants with cereals, fruits, vegetables, and legume crops has also shown promising yield and economic returns compared to their solitary cropping systems. For example, Bagheri *et al*., (2014) and Bilasvar and Salmasi (2016) reported yield advantages of intercropping maize with basil and borage, and sweet basil with corn, respectively. In addition, studies have been conducted on the intercropping of different vegetables with various crop components in different regions. Bantie (2015) discovered that intercropping potatoes with maize in the south wollo of Ethiopia resulted in yield advantages and higher economic returns than monocropping systems. Da Mota *et al.,* (2012) found a yield advantage of intercropping onions with lettuce at the highest population density compared to sole cropping. Mehdi *et al*., (2015) also reported yield and economic advantages of intercropping roselle with aloe vera. Furthermore, Jankowska *et al.,* (2012) determined that intercropping carrots with French Marigold (*Tagetes patula nana* L.) and Pot Marigold (*Calendula officinalis* L.) resulted in a yield advantage over the sole cropping system and reduced the number of roots damaged by carrot rust flies, Psila rosae, and nematodes.

### *2.2.1 Yield advantage and economic return of hot pepper (Capsicum annum L.) in intercropping system*

The cultivation of hot peppers can benefit from employing various companion crops that have demonstrated multiple advantages. Various plant species, including fruits, vegetables, forage, and aromatic and medicinal plants, have been intercropped with hot peppers belonging to more than 12 botanical families (Kahn, 2010). *Capsicum annuum* L. is frequently intercropped with tomatoes, onions, garlic, okra, Brassica species, cucurbits, pulses, and newly established perennial crops (Grubben and El Tahir, 2004). Brintha and Seran (2012) discovered that intercropping Capsicum annuum L. with onions resulted in the highest yield advantages and economic returns compared to the monoculture system. Similarly, intercropping hot peppers with other companion crops has been shown to diminish disease and pest infestation in component crops. Mitiku *et al.,* (2013) intercropped maize with hot peppers to examine the impact of intercropping on the yield and productivity of potyvirus infection and found that intercropping of both crop components was advantageous for managing diseases and insect pests, thereby enhancing productivity compared to solitary cropping systems. This may be attributed to the fact that certain neighboring plants divert pests, deterring them from the main crops (Kuepper and Dodson, 2001). A study conducted by Kabura *et al*., (2008) reported that intercropping onions in the interspaces of hot peppers, at a spacing of 60 × 30 cm with onions at a spacing of 15 × 40 cm, offered approximately 18% yield advantage over the sole cropping system. This could be due to the onions utilizing the available growth resources and microclimate, which the hot peppers did not utilize (De Pailhe, 2014). Furthermore, Pereira *et al.,* (2015) investigated the enhancement of pepper pollination by beneficial insects through intercropping with basil and found that the intercropping system exhibited greater abundance and richness of bees (Apoidea) compared to solitary cropping systems. Consequently, the fruit yield obtained from the intercropped system was wider, longer, heavier, and contained more seeds than that obtained from the solitary cropping system. Therefore, the intercropping system of hot peppers with other companion crops demonstrated yield advantages and economic returns compared with those of solitary cropping systems.

Moreover, literature has documented the economic benefits of intercropping Capsicum spp. with other companion crops. For example, in India, Prabhakar and Shukla (1990) conducted a study analyzed the economic return of intercropping Capsicum annum L. with onions. Their findings revealed a substantial increase of approximately 59% in economic returns compared with sole cropping. Similarly, an assessment of the economic advantages of intercropping hot pepper with garlic demonstrated that intercropping resulted in the highest net return when compared to the sole cropping system. Another study by Olasantan *et al*., (2007) evaluated the effects of intercropping cassava with hot pepper, and it was observed that intercropping Capsicum annum L. with cassava led to an increase in yield and total gross return compared to the sole cropping system. In a recent study conducted in Hawassa and Halaba in Ethiopia, Banjaw *et al.,* (2022) reported significant yield benefits and economic returns resulting from intercropping hot peppers with sweet basil. Additionally, Megersa *et al.,* (2018) reported the yield and economic advantages achieved by intercropping different varieties of hot pepper with varying densities of basil. Furthermore, Ram and Kumar (1998) reported a yield advantage of 36% when sweet scented geranium was intercropped with hot peppers. Consequently, it can be inferred that intercropping *Capsicum annum* L. with its companion crops offers both yield and economic advantages, especially for smallholder producers, as it enables the efficient utilization of growth resources such as solar radiation, water, and nutrients that would otherwise remain unused in a solitary cropping system.

### *2.2.2 Yield Benefits and Economic Advantages of Basil in Intercropping System.*

Basil has historically been cultivated alongside a variety of vegetable crops, which promotes sustainable agriculture according to Kuepper and Dodson (2001). Several studies have demonstrated that growing basil with various companion crops can enhance the overall productivity and well-being of both basil and its companion crops. For instance, a study by De Carvalho *et al.,* (2010) found that intercropping basil with tomatoes resulted in higher yields and economic returns than a single cropping system. The highest basil herbage yield (96.5 t $ha^{-1}$) was achieved through intercropping. Additionally, Girma *et al.,* (2015) indicated that intercropping basil with maize provided a yield advantage and increased income profitability for farmers compared to a sole cropping system. This may be attributed to the efficient utilization of growth resources, such as solar radiation, water, and nutrients, as well as the phytonutrients released by basil, which inhibit insect pest infestation in maize. Bilasvar *et al.,* (2016) also reported improved yields through intercropping basil with maize. Furthermore, Chala and Chalchissa (2022) conducted a study on the benefits of intercropping tomatoes with basil, and their findings revealed that intercropping resulted in increased yield and economic benefits.

The use of basil in intercropping systems promotes sustainable agriculture by improving the pest control. Studies have shown that intercropping basil with tomatoes can reduce B. tabaci infestation, and improve fruit quality and yield (Mutisya *et al*., 2016). Similarly, intercropping basil with kale has been shown to reduce aphid infestation and improve crop quality and yield (Tiroesele and Matshela, 2015). In a study conducted by Yarou *et al*., (2018), intercropping of basil with cabbage was examined, revealing that the presence of tropical basil in close proximity to cabbage plots resulted in a significant decrease in insect pest abundance in cabbage crops. This might be because companion crops repel harmful insects and attract beneficial insect pollinators, thereby enhancing pollination and improving crop productivity. Basils contain photochemicals that repel harmful organisms and can reduce the occurrence of diseases and insect pests in companion crops, as supported by other studies.

Basil cultivation in mixed-cropping systems, which involves intercropping with various vegetables and companion crops, is a traditional practice in many countries. This method is commonly used for home consumption and market purposes. In certain instances, intercropping basil with hot pepper has been found to be advantageous in terms of yield and economic benefits. Banjaw *et al.,* (2022) reported significant yield benefits and economic returns from intercropping hot peppers with sweet basil in Hawassa and Halaba, Ethiopia. Additionally, Megersa *et al.,* (2018) reported the yield and economic advantages achieved by intercropping different varieties of hot pepper with varying densities of basil. Therefore, intercropping with basil could improve the overall health and productivity of companion crops.

### *1.3 Limitations in intercropping systems*

The use of intercropping systems may present challenges when a singular, standardized product is essential, as these systems may lack economies of scale for labor and time management (Brooker *et al*., 2014). They are generally not considered suitable for mechanization in intensive farming regions. Consequently, despite its potential advantages, intercropping faces significant competition from large-scale intensive monoculture farming systems (Brooker *et al.,* 2015). In intercropping systems, it is difficult to employ efficient harvesting implements, and component crops may pose challenges during harvesting because of monocropping (Singh *et al*., 2013).

## 3. Summary

Intercropping involves cultivating multiple crop varieties on the same plot of land for a specific period and offers several advantages. It enhances land productivity and reduces the risk of crop failure by diversifying crops, thereby ensuring seasonal yield stability and increasing gross return per unit area. Intercropping also improves moisture and nutrient usage efficiency compared with single cropping systems. For instance, planting basil alongside hot peppers can increase the productivity of the main crop, while reducing losses due to pests, diseases, and weeds. Therefore, intercropping is an important agricultural practice that enables increased yield gains through the efficient utilization of growth resources, making it a suitable option for sustainable crop production intensification without the need for additional inputs.

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