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Intercropping system: A climate-smart approach for sustaining food security

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ABSTRACT

The present-day agriculture is facing a tremendous problem to achieve the global food security in the context of climate change scenario with ever-increasing human population. To combat with the situation, there is an urgent need to adopt proven improved technologies that can ensure food and nutritional security as well as agricultural sustainability. In this regard, adoption of appropriate cropping system can play a vital role. The age-old practice of intercropping system has multifaceted benefits for the enhancement of gross productivity and farm income under a given time. Most of the earlier studies focused to assess the benefits of an intercropping system in the light of yield enhancement and monetary advantages spatially and temporally. Moreover, recent studies highlighted other advantages such as greater ecosystem services, efficient utilization of solar radiation and CO_2, enhancement of water, and nutrient use efficiency in the mixed stand, However, in the current consequence of climate change, it is the need of the hour to re-investigate the intercropping system as a mitigation and adaptation option to encounter the ill effects of climate change in agriculture. In this regard, an attempt has been made in the review article to evaluate the potential of the intercropping system as a water, energy, nutrient, carbon, and climate-smart technology that can facilitate in achieving some of the sustainable development goals (SDGs) such as SDG 2 (zero hunger), SDG 13 (climate action), and SDG 15 (life on land).

1. INTRODUCTION

In the conventional agriculture, yield enhancement was highly prioritized to ensure the supply of the agricultural production as per the market demands. By 2023, global cereal production is forecast to be about 2819 million tonnes, which is an increase of about 1.1% from the previous year [1]. The rigorous exploitation of soils following the same monocropping practices and farming system along with the use of synthetic inputs for years has halted the biological and physiological activities of soil [2,3]. In the present context of climate change, anthropogenic activities such as agricultural activities have great roles in releasing greenhouse gases (GHG) into the atmosphere facilitating global warming. GHG emissions from agricultural practices and from the food production and distribution system are a significant contributor to global climate change [4-6]. Deforestation, often driven by agricultural expansion, also contributes to climate change by converting carbon sinks into carbon sources [7]. In addition, agricultural activities contribute to the emissions of CO_2, C_2H_4, and NOx, which are all trace gases that contribute to climate change [8]. Cline [9] gave an estimate about the potential impact of climate change on global agricultural productivity. The prediction suggests that if global warming continues at its current rate, global agricultural productivity may fall by 15.9% by the 2080s. Global warming has directly affected soil carbon losses, freshwater availability, crop yield, livestock production, and fish migration and spawning [10]. Indirectly, climate change has caused frequent floods, droughts, salinity, heat stress, and tropical cyclones, which threaten food security and biodiversity [11]. The productivity of some major field crops such as rice, maize, wheat, soybean, and sorghum is expected to be affected in [12,13]. The vegetable-based intercropping system is also remunerative that facilitates poverty alleviation and food and nutritional security to smallholders [14]. Livestock production will also be impacted, with reduced productivity and higher pests and disease incidence [15]. All the abnormalities will directly and indirectly impose negative impacts on farmers' income and livelihood security.

There have been technological innovations in agriculture but the cropping system also needs to be updated to meet the target food demand for nutrition and health. There are different types of

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crop diversification in agroecosystems; however, intercropping system in which two or more crops are grown simultaneously and spatially should be prioritized due to it greater potential to conserve soil, soil nutrients, and environment biodiversity and enhance land use resources, with maximum focus on agriculture development [16-18]. Intercropping is believed to increase the different types of above and below-ground flora and fauna of various taxa in the field level, consequently enhancing ecosystem services [19]. The land use efficiency is improved with the utilization of two or more crops simultaneously in a piece of land, thereby increasing the microbial growth and microbe activity in soil [20,21]. However, in the current consequences of climate change, there is an urgent need for the adoption of climate-smart technologies in agriculture. Among them, the potential of intercropping system can be revisited as a climate-smart technology. In the present article, an attempt has been made to evaluate the potential of intercropping system as a climate-smart cropping system.

2. INTERCROPPING FOR CLIMATE RESILIENCE AND AGRICULTURAL SUSTAINABILITY

Although intercropping is an age-old cropping system, the mixed stand contributes in maintaining the ecological soundness. Intercropping incorporates the better management of crop and soil environmental factors thereby enhancing the macro and micro climatic standards. The selection of complementary intercrops can occupy different spatial variations leading to crop intensification along with higher combined productivity as compared the monoculture [17]. Increased grain yield per unit area under intercropping indicates that less land would be required for obtaining the same quantity of yield output [22-24]. Thus, the total greenhouse gas emissions through agriculture interventions such as tillage, irrigation, and use of higher quantity of synthetic inputs for the monocropping is higher than intercropping for producing same quantity of yield [25]. Intercrops have complementary solar radiation utilization as in a mixed stand relatively shade-tolerant plants are grown in the combination with shade-intolerant for a better harvest of solar energy from a limited land area [26]. The added advantages of intercropping system make it an advanced strategy for climate-smart agriculture [27,28]. The smarter way of plant arrangement in standardized rows with varied spacing allows the better utilization of all available resources to the plant [29,30]. The benefits range from soil fertility improvements to crop climatic adaptation and water use efficiency (WUE) [31]. The varied roles of intercropping in climate-smart farming are represented in Figure 1.

Campbell *et al.* [32] stated that sustainable intensification is helpful for both mitigation and adaptation actions against climate change as it positively impacts the soil quality and increase carbon storage through crop diversification, adaptation, and productivity strategies. Thus, an intercropping system helps in the adoption of climate-smart agriculture by diversifying crops, increasing yield, and reducing risks. It allows for efficient use of land, coping with dry spells, and reducing the risk of pests and diseases [33,34]. Further, intercropping aims to increase productivity [35], enhance resilience [18], reduce greenhouse gas emissions [36], and achieve food security and nutritional security [37] and some sustainable development goals (SDG) such as SDG 2 (zero hunger), SDG 13 (climate action), and SDG 15 (life on land) [37-39]. By combining different crops in the same field, intercropping can enhance the system reliance, reduce greenhouse gas emissions, and ensure resilience against ill effects of climate change [40,41]. It also promotes the use of stress-tolerant cultivars and site-specific changes in cropping patterns, which are important aspects of climate-smart crop management [12]. Legume crops which are mostly taken as intercrops cover the soil surface due to the spreading canopy and thus reduce water loss through evaporation deep root system help in replenishing water from deeper layers and checks water and soil erosion [2,18].

2.1. Intercropping as Water-smart Technology

The main regulation approaches for efficient water utilization in intercropping are based on interspecific competition and complementarily that include crop species, irrigation, and environmental factors influencing water utilization by intercrops [42]. Water use efficiency emphasizes the irrigation potential and intercropping system acts an excellent medium of water usage in agriculture. An intercropping system supports varied crop growth plan simultaneously that contributes to the water table enhancement by increasing the water uptake and share among different crops grown spatially and temporally. Intercropping system increases the soil water conservation by reducing soil run-off, better usage of available soil water in entire systems and mostly in arid and semiarid areas to increase the WUE significantly [43]. The problem of water scarcity due to evapotranspiration and faulty irrigation practices can

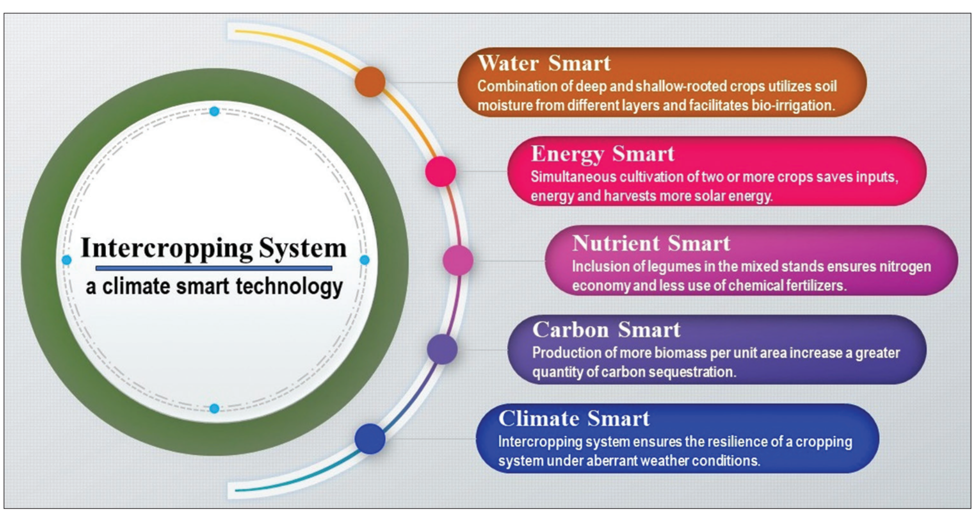

Figure 1: Importance of intercropping as climate-smart technology.

be overcome with the adoption of intercropping system that reduces the wastage of water, thereby enabling a suitable water-efficient soil conditions for better crop growth [31,44]. Healthy soils obtained by practicing intercropping system can enhance the soil's water-holding capacity and reduce the risk of soil compaction. This contributes to better water and availability for the plants. As a water-smart farming practice, intercropping aims to optimize water use and promote sustainable water management and can be considered as a water-smart technology [45]. Under scarce soil moisture conditions, some crops in the mixed stand may still thrive, even if others experience reduced growth [46]. Intercropping system utilizes cropland water through better plant roots, thereby increasing the water storage in root zone, reduces the inter-row evaporation, and decreases transpiration to create a special microclimate advantageous to the plant growth and development [47]. Evaporation decreases and WUE gets higher with intercropping [48]. Similar findings have also been observed by researchers who recorded an enhanced WUE in intercropping system and are tabulated in Table 1.

Hydraulic lift is a process when water is transferred from deep soil layers to dry topsoil layers through the plant roots due to differential gradient in soil water potential. The deeper and dimorphic roots obtain maximum water during the wet season and switch the water to subsoil during dry season [55]. Bio-irrigator plants help in hydraulic lifts of around 58% of water and it not only benefits themselves but it also facilitates its neighboring shallow-rooted plant to move out of drought [56]. The legumes having tap root system can reach deeper layers than the fibrous-rooted cereals. It has been documented that pigeon pea can lift water through hydraulic force and is a common choice in finger millet intercropping system [57]. Under the combination of deep and shallow-rooted crop mixture, the deep-rooted crop species plays the role of bio-irrigator by providing bio-irrigation to the shallow-rooted crops [58].

Table 1: Enhanced WUE under intercropping system.

Research findings in favor of enhanced WUE under intercropping	References
Increase in WUE by 18% in intercropping system over sole cropping	[49]
WUE of maize wheat intercropping was 25% higher than sole wheat	[50]
WUE of maize-rape intercropping was 152% higher than sole wheat	[50]
Maize-pea intercropping system showed 95% higher WUE over sole pea	[50]
Maize-black gram intercropping system showed 48% higher WUE than sole maize	[51]
The gross WUE of maize+soybean (2:2) was 39.6% higher than sole soybean	[44]
WUE of sole soybean and sole maize was 12.4 and 41.5 kg/ha/mm, respectively, however, intercropping maize+soybean (4:2) registered 38.75 kg/ha	[52]
WUE increased by 14% over sole wheat and by 35% over sole maize in wheat-maize intercropping	[53]
An increase in WUE in maize–pea intercropping system by 21 to 28%	[54]

WUE: Water use efficiency

2.2. Intercropping as Energy Smart Technology

Resource conservation technologies in agriculture have shown better results in enhancing crop productivity, conserving water and energy, reducing greenhouse gas emissions, and improving soil health. Intercropping in agriculture can play a significant role in diminishing overall energy consumption and contributing to more sustainable food production systems. Intercropping integrates all renewable energy systems, such as solar panels, wind turbines, or biomass production, on farmlands [59]. Intercropping compliments agroecological principles, focusing on sustainable, low-input farming systems by maintaining agroecology. Intercropping reduces the energy-intensive inputs such as synthetic fertilizers, pesticides, and herbicides due to the combination of different crops and reduces the dependence on chemical inputs and requirements for their production and application [18,60]. The increased productivity in intercropping enhances soil organic matter accumulation and carbon sequestration [61]. Moreover, intercropping system utilizes the available growth resources in a complementary way which might not be utilized efficiently by the sole crops that rely on high-energy inputs [62].

2.3. Intercropping as Nutrient Smart Technology

Intercropping is associated with nutrient-smart practices offering solutions to manage nutrients, increase crop productivity from unit area, and mitigate environmental impacts. The importance of nutrient fluxes, uptake, accumulation, and distribution in plants is responsible for improving nutrient efficiency, crop yield, and environmental concerns [63]. Intercropping increases nitrogen use efficiency (NUE) through various mechanisms [64]. One way is by optimizing the management of nitrogen fertilizer, such as postponed topdressing, which can increase the translocation of dry matter to grain in crops under intercropping system [65]. Another way is through shoot-root interactions, where increased light interception and extended duration of photosynthesis provide more synthesis of assimilates for achieving yield potential and maintaining root growth, leading to improved NUE [66]. In addition, intercropping systems can better match temporal and spatial N supply with crop demand, resulting in improved N nutrition index and enhanced yield components [26]. Furthermore, intercropping can exploit species complementarities, such as in cereal-legume intercropping total crop productivity is increased with reduced synthetic fertilizer N use [53]. Intercropping cereals with legumes, such as maize-legume intercropping, facilitates biological nitrogen fixation, leading to improved soil fertility and land-use efficiency [12]. Intercropping has been found to increase the NUE in many other intercropping systems [Table 2].

2.4. Intercropping as Carbon Smart Technology

The efficiency of an intercropping system in decreasing carbon emissions can be determined properly with changing agroecological circumstances as different growing conditions such soil moisture, temperature, and precipitation affect the crop production in all cropping systems [70]. The dry matter/biomass is directly proportional to the carbon efficiency of crops and intercropping helps in improving the carbon sequestration efficiency. The incorporation of legume crops in the cropping system decreases the additional nitrogen application and lowers the C footprint in agriculture [71]. In a study, it was found that maize-peas intercropping significantly reduced carbon emission (2.8 t/ha) which was around <31% sole maize and the study revealed that among all the intercropping systems tested, the maize soybean produced the lowest carbon emissions [72]. Therefore, intercropping legumes with cereals can be considered as an excellent cropping system in increasing crop productivity as well as reduced C footprints in agriculture. According to Leite *et al*. [73], it was observed that the total nitrogen and total carbon contents in soil were increased whereas the carbon-to-nitrogen ratio was decreased by adoption of intercropping system.

Similar research carried out in China revealed that CO_2 emissions were reduced by more than 15% with the sorghum-cowpea intercropping which also emitted less CO_2 at 28 and 76 days after sowing in sole when grown as sole crop [74]. Crop biomass is a product of solar energy which this energy is stored by carbon dioxide fixation through photosynthesis and this carbon per unit of water in intercropping was less by 42, 52, and 45%, respectively, in 3 consecutive years [75]. The emission of greenhouse gases generally remains higher due to crops with higher energy levels but legumes in the mixed stand modify it by making intercropping an efficient cropping system [76]. The effectiveness of biological nitrogen fixation also represents lower CO_2 emission [77], with a decreased synthetic nitrogen fertilizer input [71]. Intercropping systems along with conservation tillage reduced the CO_2 emissions and increased the soil organic carbon [53]. The grain sorghum-cowpea intercrop with high- and low-density planting of cowpea also decreased the CO_2 emission rates in soil by increasing the soil carbon stocks and enhancing the carbon use efficiency [78]. Earlier researchers evidenced the climate smartness of intercropping systems [Table 3].

2.5. Intercropping as Climate-smart Technology

Under the present consequences of climatic conditions, an intercropping system increases yield stability, higher economic output offering an adaptation to climate change. Intercrops might be considered a safe and natural insurance policy with extreme weather getting more prevalent. Intercropping system offers a resilience under harsh climatic conditions. In earlier research, Xie *et al*. [82] proved that maize and potato intercropping system offered a superior condition to manage the harsh climatic conditions in the Loess Plateau in China as the intercropping system provided higher land equivalent ratio (>1) compared to sole cropping. Interestingly, the intercropping system tackled scarce soil moisture conditions and a greater WUE with a higher energy output over the pure stand of maize or potato. Further, crop diversification with the inclusion of legumes is considered a strategy that enhances a greater above and below-ground variation in flora and fauna and safeguards a greater ecosystem service [83,84]. Further, legumes fix nitrogen in the mixed stand and share a portion with non-legume and thus play a vital role by substituting nitrogen needs of the cropping system. The production of synthetic nitrogenous fertilizer generates GHGs which are released into the atmosphere [85]. Recent estimates prepared by FAO [86] mentioned that nitrogenous fertilizer production alone is responsible for 0.41 $GtCO_2$ GHG emission which is equivalent to 0.7% of global GHG emission [28]. In this context, the role of legumes in an intercropping system is further elevated as a climate-smart approach. In a combination of tall and dwarf species mixture, taller plants minimize wind speed by reducing shade which reduces the impact of soil moisture deficit and high temperature stress on crops in the mixed stand [27]. In alley cropping or agroforestry, because of the presence of short and dwarf-stature plants, an alteration in wind movement is prominent [87]. Such altered aeration minimizes air pollution and declines temperature and thus creates a microclimate [27]. In case of mixed stand of annual crops, a soothing microclimate is created in the crop field due to more coverage of land by vegetation facilitating healthy growth of crops under weather extremes [35,88]. Further, in sole cropping, to obtain higher grain or biomass yield, more inputs are utilized resulting in the generation of GHGs as well as higher carbon footprint (CF) in agriculture. On the other hand, from the same piece of land, more biomass output is obtained in an intercropping system that ultimately reduces CF. In a study, Sun *et al.* [89] reported that intercropping maize + wheat resulted in the lowest CF per maize equivalent energy yield and the maize + potato registered the lowest CF per unit economic output in water deficient region of northwest China. The above-mentioned facts have designated the intercropping system as a climate-smart technology.

Table 2: Impact of intercropping on nitrogen use efficiency.

Salient findings	References
Cotton+peanut intercropping showed 53% higher NUE than sole peanut	[67]
NUE of pea+barley intercropping was 10–14% higher than sole crop of pea	[68]
Pea+barley intercropping used nitrogen sources 20–30% more efficiently than sole crops	[69]

NUE: Nitrogen use efficiency

Table 3: Carbon smartness of different intercropping systems.

Salient findings	References
Intercropping reduced the carbon emissions by 18.9% compared to monoculture	[79]
Wheat-maize intercropping can reduce carbon emission by 7% than monoculture maize	[53]
Carbon efficiency of groundnut–bean intercrop system was 32.67% higher than sole groundnut	[80]
The intercropping of maize with wheat emitted 42% less carbon, maize with rape emitted 52% less carbon, and maize with pea emitted 45% less carbon	[50]
A higher carbon sequestration by 5.3% in intercropping of sunflower cowpea than sole sunflower	[81]

3. CONCLUSION

The intercropping system, an old cropping system, is recognized for its multifaceted benefits for yield stability, profitability, and agricultural sustainability. Interestingly, it is equally relevant in the current consequences of climate change when climatic aberrations are hindering the bumper harvest and making farmers far from agricultural sustainability. The review article clearly focused on the various aspects of climate smartness of the intercropping system such as water, energy, nutrient, carbon, and climate-smart approaches which can ensure agricultural sustainability. The intercropping system is potentially important today for the efficient utilization of available resources such as water, sunlight, nutrients, atmospheric carbon, and energy. Further, harnessing the above-mentioned benefits will keep the present agriculture one step ahead in achieving some of the SDG, namely SDG 2 (zero hunger), SDG 13 (climate action), and SDG 15 (life on land).

4. AUTHORS' CONTRIBUTIONS

All authors made substantial contributions to conception and design, acquisition of data, or analysis and interpretation of data; took part in drafting the article or revising it critically for important intellectual content; agreed to submit to the current journal; gave final approval of the version to be published; and agreed to be accountable for all aspects of the work.

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6. CONFLICTS OF INTEREST

The authors report no financial or any other conflicts of interest in this work.

7. ETHICAL APPROVALS

This study does not involve experiments on animals or human subjects.

8. DATA AVAILABILITY

All data generated and analyzed are included within this review article.

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