Plant Archives Vol. 25, No. 1, 2025 pp. 1393-1399 e-ISSN:2581-6063 (online), ISSN:0972-5210

Plant Archives

Journal homepage: http://www.plantarchives.org

DOI Url : https://doi.org/10.51470/PLANTARCHIVES.2025.v25.no.1.206

INTERCROPPING – AN APPROACH TOWARDS SUSTAINABILITY IN AGRICULTURE

B.V. Pawar[1*], A.B. Chorey[2], R.H. Wakde[3], P.S. Dudde[1], A.S. Ekapure[4] and A.S. Bayskar[1]

[1]Department of Agronomy, PGI, Dr. Panjabrao deshmukh krishi vidyapeeth, Akola (Maharashtra), India.
[2]All India research project for dryland agriculture, PDKV, Akola (Maharashtra), India.
[3]Department of Agronomy, College of Agriculture, Latur. Vasantrao Naik Marathwada Krishi Vidyapeeth, Parbhani (Maharashtra), India.
[4]Department of Soil Science, PGI, Dr. Panjabrao Deshmukh Krishi Vidyapeeth, Akola (Maharashtra), India.
*Corresponding author E-mail: pawarbhakti9099@gmail.com

(Date of Receiving-12-02-2025; Date of Acceptance-15-04-2025)

ABSTRACT

Modern agriculture is facing significant challenges due to climate change and the growing human population. Even slight climate variations can negatively impact agriculture, leading to reduced crop yields. To minimize these issues, adopting advanced and sustainable farming techniques is very important. One such approach is the implementation of appropriate cropping systems, with intercropping emerging as a highly beneficial practice. Intercropping, an age-old farming method, involves growing two or more crop species or genotypes together for the specific period. This provides various advantages, including enhanced overall productivity and increased farm income within a given timeframe. Moreover, intercropping contributes to agroecosystem stability by improving resource efficiency, increasing soil water retention, maximizing solar energy utilization, reducing GHG emissions, increasing carbon sequestration and providing greater ecosystem services. While modern intensive agriculture often overlooks intercropping, it remains vital for subsistence and low-input farming systems. Integrating legumes such as soybean, groundnut, black gram, and French bean with primary crops has proven effective in optimizing upland productivity, minimizing crop failure risks, stabilizing yields, improving resource utilization, and maintaining soil fertility. Additionally, this practice boosts farmers' incomes and enhances food and nutritional security for their households.

Keywords: Intercropping, Climate change, Sustainability, Cropping System, carbon sequestration)

INTRODUCTION

Indian agriculture experiencing climate change effect, particularly drought, as two-thirds of the country's land is rainfed, and even the irrigated system depends on monsoon rains. In several regions of the nation, particularly the eastern one where floods occur frequently, flooding is another significant issue. Furthermore, cyclones on the eastern coast, heat waves in the middle and northern regions, and frost in the northwest all cause devastation. Due to the rising air temperature in the recent years, these climatic extremes have become more frequent, increasing the hazards and causing a significant loss in agricultural output. The crops, soils, animals, and pests are all directly and indirectly affected by climate change. Temperature increases can shorten crop duration, rise respiration rates, change the process of photosynthesis. They can also increase the mineralization of nutrients in soils, reduce the efficacy of fertilizer use, and increase evapotranspiration. (Gupta and Pathak, 2016). Climate change is having a negative impact on India's agriculture industry. To overcome these challenges, policymakers believe that understanding and adapting to farmers' impressions of the quickly changing climate is essential (Datta *et al.*, 2022)

In the occurrences of climate change, agriculture sector would face the following significant challenges: (i) Water scarcity due to altered rainfall patterns, stream flow, and increased crop water demand; (ii) deterioration of water quality due to intrusion of seawater; and (iii) Transport of salts from the deeper soil layers due to the improper irrigation techniques and overexploitation of aquifers. (iii) More frequent and hazardous weather events, like severe water scarcity, floods and cyclones, which would have a greater impact on production levels than average climate change (Gupta and Pathak, 2016).

Intercropping is a practice of growing two or more crop species or genotypes in the same field, is a multi-faceted farming approach that leverages the distinct qualities and interactions of various crops to offer an eco-friendly alternative to traditional farming methods (Brooker *et al.*, 2023). By increasing resource use efficiency, enhancing soil water holding capacity, and expanding the diversity and quality of pollinator habitat for insects such offer pollination services and natural pest control, intercropping helps fortify and stabilize agroecosystems in the context of climate change (Huss *et al.*, 2022). There are several spatial configurations in which intercropping can be used. With mixed intercropping, several crops are grown concurrently without specific row configurations (Agegnehu *et al*., 2008). Using row intercropping, secondary plants are planted in rows that alternate with the primary crop (Chen *et al*., 2004). Strip intercrops are grown in strips that are both sufficiently wide for individual cultivation and sufficiently narrow to allow for ecological interaction between each crop (Li *et al*., 2001, Brennan, 2016).

There are a number of fundamental advantages of intercropping that are pertinent in the current context of changing climatic scenario, including the ability to assure the regulation of climatic factors, efficient soil moisture utilization, maximum use of solar radiation, reduced GHG emissions, enhanced carbon sequestration, and greater ecosystem services (Maitra *et al*., 2023).

The Potential of Intercropping in Facing Climate Change

Intercropping has been shown to have several benefits, although it is acknowledged that these benefits vary depending on the intercrops and the type of intercropping. These benefits include increased yield security, soil conservation, water dynamics regulation, pathogen buffering, increased nutrient and protein self-sufficiency, and a decrease in the need for external inputs based on fossil fuels. Intercropping, then, can be seen as a way to increase farm adaptive capacity as well as a targeted adaptive technique and a potential climate-smart practice that can be grown locally and context-specifically (Himanen *et al.*, 2016). By increasing plant resource efficiency (space, nutrients, and water) and naturally suppressing weeds, diseases, and insect pests, intercropping can increase climate resistance. When combined, these effects frequently increase farmer's profitability (Ward *et al.*, 2016).

Even though intercropping is an old cropping system, the mixed stand helps to maintain ecological soundness. By improving the management of crop and soil environmental factors, intercropping raises the macro and microclimatic standards. By choosing complementary intercrops, one can increase crop intensification and overall productivity compared to monoculture (Li *et al.*, 2020). In order to produce the same amount of yield, monocropping requires more synthetic inputs, tillage, and irrigation than intercropping, which results in increase overall GHG emissions (Jayathilake *et al*., 2021).

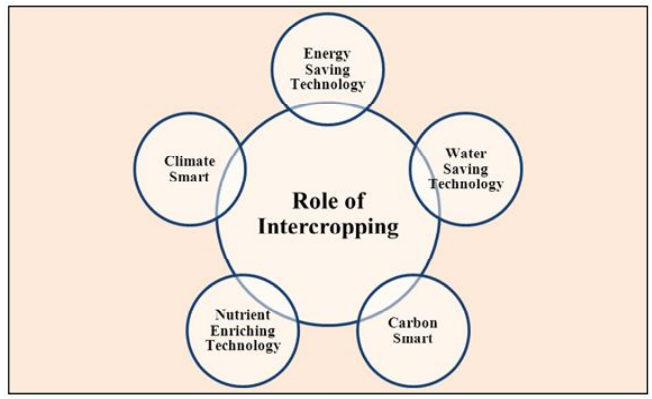

Fig.1: Role of intercropping in changing climatic scenario.

Intercropping as an Energy Saving Technology

Crop productivity, energy and water conservation, GHG emissions, and soil health have all improved with the application of resource conservation methods in agriculture. In agriculture, intercropping can significantly decrease total energy usage and encourage of sustainable food production systems. On farmlands, intercropping incorporates all forms of renewable energy, including biomass generation, wind turbines, and solar panels (Sahoo *et al.*, 2024). Kishore *et al.*, (2025) reported that the higher energy input was estimated in Mango + dragon fruit + pineapple, Mango + Pineapple and Mango + Dragon fruit system. Energy input of Mango + Dragon fruit + Pineapple system was ~2.7 times greater than monocropping, whereas in other intercropping system, energy input was about two times greater than monocropping. In comparison, intercropping systems require less energy inputs such as fertilizer, fewer chemicals for plant protection, and more crop diversification, which creates functional diversity and lowers the prevalence of pest diseases. A calming environment with reduced evaporation is also created

(Maitra *et al.,* 2021). Energy output, energy input and EUE was more in paired-row planted maize + soybean over sole maize (Kumar *et al.,* 2015)

Baishya *et al.,* (2020) carried out an experiment for evaluation of Maize (*Zea mays* L.) based intercropping system for Productivity, Profitability, Energy budgeting and soil health in Eastern Himalayan Region the result indicated that the lowest energy input, Output energy, Net energy, Energy efficiency and Energy productivity were with the sole cropping of cowpea 7.75 x 103 MJ ha^{-1}, 72.85 x 103 MJ ha^{-1}, 65.09 x 103 MJ ha^{-1}, 9.39 and 644.44 g MJ^{-1} respectively and maize + groundnut (1:1) recorded the highest, Input energy, Output energy, Net energy, Energy efficiency and Energy productivity 10.68 x 103 MJ ha^{-1}, 148.61 x 103 MJ ha^{-1}, 137.93 x 103 MJ ha^{-1}, 13.91 and 955.01 g MJ^{-1} respectively.

Water Use Efficiency under Intercropping

Crop water usage efficiency (WUE) can be improved through intercropping, which also optimizes the soil moisture condition for crop growth. Because of its high and consistent yield and effective use of the resources, strip intercropping has been used extensively in arid and semi-arid climate (Yin *et al.,* 2020). Intercropping systems could improve water storage in the root zone, reduce inter-row evaporation and control excessive transpiration, promote the full use of farmland water by plant roots, and create a special microclimate that is advantageous to plant growth and development (Dugassa, 2023). It can also improve retention of fertilizers applied by reducing water runoff and erosion (Andrews *et al*., 2020). Over half the fertilizer applied to cropland worldwide is lost to leaching and denitrification, polluting waterways, and releasing greenhouse gasses (Lassaletta *et al.,* 2014). Intercrops can help reduce this pollution because their roots hold the soil in place and their leaves reduce the effect of rains. Additionally, intercropped plants save water by lowering soil evaporation rates and shade the soil surface with a bigger plant canopy (Wallace *et al*., 1999), while intercrops might lessen water conflict because to complementing root architecture (Yin *et al.,* 2020). Intercrop residue increases soil OM, which can significantly increase the soil's ability to hold water and nutrients. In fact, the amount of water accessible for plants doubles when soils contain 1% to 3% more organic matter (Hudson, 1994). The intercropping is a agricultural strategies which help in increase water productivity (Metwally *et al.,* 2019). In order to generate a unique microclimate that is beneficial to plant growth and development, intercropping systems use agricultural water through improved plant roots, improving water storage in the root zone, reducing inter-row evaporation, and decreasing transpiration (Shaoo *et al.,* 2024).

When compared to flood irrigation, an alternative irrigation technique decreased the quantity of water used for intercropping by 16.1% and 15.3% at high and low water supply levels, respectively (Yang *et al.,* 2011). Following intercropping, ideally of deep-rooted crops with shallow-rooted crops, increases WUE because intercropping uses comparatively less water for irrigation to produce yields that are equivalent (Singh *et al.* 2014). Singh *et al*., (2019) performed research on the intercropping pattern of wheat and chickpea and reported that the intercropping system of Wheat + chickpea (2:1) gave higher WUE than sole wheat *i.e.* 0.117 and 0.083 Mg ha^{-1} cm^{-1} respectively. Bharati *et al.,* (2007) carried out an experiment during winter season of 2002-03 and 2003-04 at Pusa in Bihar to study effect of four irrigation levels, based on Irrigation water (IW): cumulative pan evaporation (CPE) ratio and four intercropping systems. The study indicated that there was also significant effect in water requirement due to different intercropping systems. In both the years water requirement was lowest in maize + rajmash as compared to the sole system.

Intercropping as a Carbon-smart Technology

Changing agroecological variables can accurately assess how effective an intercropping system is at reducing carbon emissions because crop output in all cropping systems is impacted by various growth component, including soil moisture, temperature and precipitation (Lemke *et al.,* 2007). Intercropping offers the ability to enhance the soil's structural integrity, encourage the sequestration of soil organic carbon, and guarantee the highest possible crop yield when paired with fertilizers that contain organic additions (Moreira, 2024). Abbady *et al*., (2016) carried out experiment at El-Giza agricultural research station to examine the short-term effects (3 years) of two cropping patterns-based on intercropping system and N fertilization on quantifying of crop& soil carbon sequestration and soil carbon dioxide emissions targeting to test the ability of this management to mitigate global warming. The results shows that intercrops patterns and urea form fertilizer have been contributed to obtain a lower emitted CO_2 quantities from soil compared to sole crops patterns and urea fertilizer. A higher carbon sequestration by 5.3% in intercropping of sunflower cowpea than sole sunflower. Yin *et al.,* (2017) carried out a field experiment using an improved system was conducted at an arid oasis region in north western China in 2014, 2015, and 2016. The result revealed that the carbon emissions of wheat/maize intercropping pattern were 18.9% lower than maize monoculture.

Among the various cropping systems, Coconut + Jamun system sequestered the highest up above carbon (60.93 t ha^{-1}) subsequently Coconut + Mango system with 56.45 C t ha^{-1}, Coconut + Garcinia sequestered 53.02 C t ha^{-1} whereas, coconut alone had sequestered 51.14 C t ha^{-1}. The underground soil carbon stock in the rhizosphere of 0 to 60 cm depth was the highest in coconut + mango (82.47 t ha^{-1}) system subsequently Coconut + Jamun (79.13 t ha^{-1}), Coconut + Garcinia (78.69 t ha^{-1}) and it was the lowest in coconut monocrop (47.06 C t ha^{-1}) (Bhagya *et al.,* 2017). The wheat/maize intercrops increased net primary production by 68% and net ecosystem production by 72%; and when combined with straw mulching on the soil surface, it decreased carbon emissions by 16%, compared to the monoculture maize without mulch (Hu *et al.,* 2016).

Nutrient Use Efficiency under Intercropping

In species with different rooting and uptake tendencies, such as those cultivated in cereal-legume intercropping systems, higher N-uptake in the intercrop has been seen in comparison to mono-cropping (Dugassa, 2023). Complementary intercrops require different forms and quantities of nutrients meaning they can coexist with relatively little competition (Li *et al.,* 2020). Soil N, P, and K concentrations are reported to be higher when maize and cowpeas are planted together than when maize is grown alone (Mugwe *et al.,* 2011). Efficient allocation of soil nutrients to plants reduces the need for synthetic fertilizers (Xu *et al.,* 2020). Since nitrogen-fixing plants enhance the nitrogen budgets of cereal and oilseed crops and further lessen the requirement for synthetic fertility, they are most often used as intercrops (Jensen *et al*., 2020). Living mulch intercrops reduce the occurrence of important nutrient deficits by allowing complementing plants to effectively share micro and macronutrients through shared mycorrhizal networks, increasing nutrient usage efficiency (Zuo *et al*., 2000, Dowling *et al.,* 2021). Indeed, if land currently used for cereal crops worldwide was converted to cereal-legume intercrop systems, nitrogen-based fertilizer use could be decreased by 26% (Jensen *et al.,* 2020), which could shrink the carbon footprint of agriculture.

Intercropping is a revolutionary approach to enhancing soil fertility and health in sustainable agriculture. This method enables the soil ecology to benefit from a large number of plant species cooperating by cultivating numerous crops close to one another. Numerous studies have examined the amazing capacity of intercropping systems to raise soil nutrient levels, particularly those of nitrogen (N) and phosphorus (P), as well as to foster diverse and robust microbial communities (Toker *et al*., 2024). By recovering nutrients from beneath the crop's root zone, intercropping systems help to create a more sustainable and effective nutrient cycle (Lorenz and Lal, 2014). The highest total N (108.4 kg/ha), P (12.50 kg/ha) and K (109.70 kg/ha) uptake was recorded in the treatment with finger millet (HR-374)+ pigeon pea (6:2) (Mahto *et al.*, 2007). Nyawade *et al*., (2020) Highlighted that intercropping with legumes reduces the dropping of nitrogen from the soil, increases productivity and increases the efficacy of nutrient use. It also improves drought resistance in shallow soil plants by encouraging deeper root growth, leading to higher growth rates and nutrient levels in leaves.

Intercropping as a Climate-smart Technology

In the events of climate change and an ever-growing human population, modern agriculture faces enormous challenges in attain global food security. Adopting tested, enhanced technology that can guarantee food and nutritional security as well as agricultural sustainability is imperative in order to tackle the issue. Choosing the right cropping system can be crucial in this respect. The long-standing intercropping strategy provides several advantages for raising farm income and gross production over a specific period of 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 current consequence of climate change, it is the essential requirement to re-investigate the intercropping system as a mitigation and adaptation option to encounter the ill effects of climate change in agriculture (Sahoo *et al.*, 2024).

Agricultural interventions including tillage, irrigation, and use of more synthetic inputs for monocropping result in higher overall GHG emissions than intercropping for the same yield (Jayathilake *et al.*, 2021). Intercropping of foxtail millet + pigeonpea (5:1) was identified as best climate resilient system in black soils (kurnool district) of Andhra Pradesh. This system on an average enhanced pigeonpea seed equivalent yields by 406 and 191 kg/ha compared to sole crops of foxtail millet and pigeonpea and recorded 41% of yield advantage over sole crops. In Aurangabad district of Maharashtra, soyabean + pigeonpea (4:2) and pigeonpea + green gram (1:2) were identified as climate resilient intercropping systems. Cotton + greengram (1:1) intercropping system was suitable during medium and good rainfall years in black soils of

Aurangabad district. In Nandurbar district of Maharashtra, soybean + pigeonpea (3:1) was found stable over different rainfall patterns. On an average, the intercropping system of soybean + pigeonpea (3:1) recorded 73% higher net income than sole pigeonpea (Shekar *et al.,* 2019).

Conclusion

Intercropping, the practice of growing two or more crop species or genotypes within a same field, is a versatile farming method that harnesses the unique traits and interactions of different crops to provide an environmentally friendly alternative to conventional agriculture. This system helps regulate climatic conditions, optimize soil moisture usage, enhance nutrient use efficiency, maximize solar radiation absorption, lower greenhouse gas emissions, increase carbon sequestration, and enhance ecosystem services. The diverse crop mixture supports ecological stability while promoting better management of soil and crop environments, ultimately improving both macro and microclimatic conditions.

References

Abbady, K., El-Maaz, E., Ahmed, H. and Zohry A. (2016). Carbon sequestration as a function of intercropping management practice and different nitrogenous fertilizer types. *J Soil Sci Agric Eng* 2016; **7:**565-86.

Agegnehu, G., Ghizaw, A. and Sinebo, W. (2008). Yield potential and land-use efficiency of wheat and faba bean mixed intercropping. *Agron. Sustain. Dev.,* **28:** 257–263.

Andrews, J. S., Sanders, Z. P., Cabrera, M. L., Hill, N. S. and Radcliffe, D. E. (2020). Simulated nitrate leaching in annually cover cropped and perennial living mulch maize production systems. *J. Soil Water Conserv.,* **75:** 91–102.

Baishya, L.K., Temjenna, J., Walling, N. and Rajkhowa, D.J. (2020). Evaluation of maize (*Zea mays* L.) + legume intercropping system for productivity, profitability, energy budgeting and soil health in hill terraces of Eastern Himalayan Region. *Legume Research- An International Journal*, 10.18805/LR-4190.

Bhagya, H.P., Maheswarappa, H.P., Surekha. and Bhat, R. (2017). Carbon sequestration potential in coconut-based cropping systems. *Indian Journal of Horticulture,* **74(1):**1.

Bharati, V., Nandan, R., Kumar, V. and Pandey, I. B. (2007). Effect of irrigation levels on yield, water use Efficiency and Economics of winter maize (*Zea mays*)- based intercropping systems *Indian Journal of Agronomy,* **52(1):** 27-30.

Brennan, E. B. (2016). Agronomy of strip intercropping broccoli with alyssum for biological control of aphids. *Biol. Control*, **97:** 109–119.

Brooker, R. W., Hawes, C., Iannetta, P. P., Karley, A. J., Renard, D. and Schmid, B. (2023). Plant diversity and ecological intensification in crop production systems. *Journal of Plant Ecology*, **16(6)**.

Chen, C., Westcott, M., Neill, K., Wichman, D. and M. Knox. (2004). Row configuration and nitrogen application for barley-pea intercropping in Montana. *Agron. J.*, **96:** 1730–1738.

Datta, P., Behera, B. and Rahut, D. B. (2022). Climate change and Indian agriculture: A systematic review of farmers' perception, adaptation, and transformation. *Environmental Challenges,* **8:** 100543.

Dowling, A., Sadras, V. O., Roberts, P., Doolette, A., Zhou, Y. and Denton, M. D. (2021). Legume-oilseed intercropping in mechanised broadacre agriculture-A review. *Field Crops Res.,* **260:**107980.

Dugassa, M. (2023). Intercropping as a multiple advantage cropping system: Review. *International Journal of Research in Agronomy,* **6(1):** 44-50.

Gupta, A and Pathak, H., (2016). Climate Change and Agriculture in India. New Delhi: page no. 4.

Himanen, S. J., Makinen, H., Rimhanen, K. and Savikko, R. (2016). Engaging Farmers in Climate Change Adaptation Planning: Assessing Intercropping as a Means to Support Farm Adaptive Capacity. *Agriculture,* **6(3):** 34.

Hudson, B. D. (1994). Soil organic matter and available water capacity. *J. Soil Water Conserv.,* **49:** 189–194.

Hu, F., Gan, Y., Cui, H., Zhao, C., Feng, F., Yin, W. and Chai, Q. (2016). Intercropping maize and wheat with conservation agriculture principles improves water harvesting and reduces carbon emissions in dry areas. *European Journal of Agronomy,* **74:** 9-17.

Huss, C. P., Holmes, K. D. and Blubaugh, C. K. (2022). Benefts and Risks of Intercropping for Crop Resilience and Pest Management. *Journal of Economic Entomology*, **115(5):** 1350–1362.

Jayathilake, H. M., Prescott, G. W., Carrasco, L. R., Rao, M. and Symes, W. S. (2021). Drivers of deforestation and degradation for 28 tropical conservation landscapes. *Ambio*, **50(1):** 215–228.

Jensen, E.S., Carlsson, G. and Hauggaard-Nielsen, H. (2020). Intercropping of grain legumes and cereals improves the use of soil N resources and reduces the requirement for synthetic fertilizer N: a global-scale analysis. *Agron. Sustain. Dev.,* **40:** 1–9.

Kishore, K., Sangeetha, G., Rupa, T. R., Ganeshmurthy, A. N., Samant, D., Acharya, G. C. and Srinivas, P. (2025). Assessment of mango-based intercropping systems for productivity, resource use efficiency and environmental sustainability in tropical region of India. *Next Sustainability,* **5:** 100-121.

Kumar, A., Rana, K. S., Rana, D. S., Bana, R. S., Choudhary, A. K. and Pooniya, V. (2015). Effect of nutrient-and oisture-management practices on crop productivity, water-use efficiency and energy dynamics in rainfed maize (*Zea mays*)+ soybean (Glycine max) intercropping system. *Indian Journal of Agronomy,* **60(1):** 152-156.

Lassaletta, L., Billen, G., Grizzetti, B., Anglade, J. and Garnier. J. (2014). 50 year trends in nitrogen use efficiency of world cropping systems: the relationship between yield and nitrogen input to cropland. *Environ. Res. Lett.*, **9:** 105011.

Lemke, R. L., Zhong, Z., Campbell, C. A. and Zentner, R. P. (2007). Can pulse crops play a role in mitigating greenhouse gases from North American agriculture. *Agron J.* 007; **99:** 1719-25.

Li, C., Hoffland, E., Kuyper, T. W., Yu, Y., Li, H., Zhang, C., Zhang, F. and Van der Werf. W. (2020). Yield gain, complementarity and competitive dominance in intercropping in China: a meta-analysis of drivers of yield gain using additive partitioning. *European J. Agron*., **113:** 12598.

Li, C., Hoffland, E., Kuyper, T. W., Yu, Y., Zhang, C., Li, H., Zhang, F. and Werf, V. W. (2020). Syndromes of production in intercropping impact yield gains. *Nat Plants,* **6(6)**: 653-660.

Li, L., J. Sun, F. Zhang, X. Li, S. Yang, and Z. Rengel. (2001). Wheat/maize or wheat/soybean strip intercropping: I. Yield advantage and interspecific interactions on nutrients. *Field Crops Res*., **71:** 123–137.

Lorenz, K. and Lal, R. (2014). Soil organic carbon sequestration in agroforestry systems. A review. *Agronomy for Sustainable Development,* **34:** 443-454.

Mahto, D. K., Ahmed, S., Singh, S. and Srivastava, G. P. (2007). Soil fertility and nutrient uptake in fingermillet (*Eleughine coracona* L.) based intercropping systems. *Journal of Research, Birsa Agricultural University,* **1:** 87-90.

Maitra, S., Hossain, A., Brestic, M., Skalicky, M., Ondrisik, P., Gitari, H., Brahmachari, K., Shankar, T., Bhadra, P. and Palai. J. B. (2021). Intercropping-A Low Input Agricultural Strategy for Food and Environmental Security. *Agronomy,* **11(2):** 343.

Maitra, S., Sahoo, U., Masina, S., Gitari, H. I., Esmaeil, R.C., Battaglia, M. L. and Hossain, A. (2023). Cultivating sustainability: A comprehensive review on intercropping in a changing climate. *Res. Crop.,* **24:** 702-715.

Metwally, A. A., Abdel-Wahab, T. I. and Abdel-Wahab, S. I. (2019). Increasing Land and Water Use Efficiencies by Intercropping Summer Legumes with Corn in Egypt. *Agric Biol Res*, **35:** 6-12.

Moreira, B., Goncalves, A., Pinto, L., Prieto, M. A., Carocho, M., Caleja, C. and Barros, L. (2024). Intercropping Systems: An Opportunity for Environment Conservation within Nut Production. *Agriculture*, **14(7):** 1149

Mugwe, J., Mugendi, D. N., Mucheru-Muna, M. and Kungu. J. (2011). Soil inorganic N and N uptake by maize following application of legume biomass, tithonia, manure and mineral fertilizer in Central Kenya. *Springer,* p. 605-616.

Nyawade, S.O., Karanja, N. N., Gachene, C. K., Gitari, H. I., Schulte-Geldermann, E. and Parker, M. (2020). ptimizing soil nitrogen balance in a potato cropping system through legume intercropping. *Nutrient cycling in Agroecosystems*, **117:** 43-59.

Reddy, G. R., Prasad, Y. G., Osman, M., Himabindu, T., Raju, B. M. K., Sudhakar, N. and Rao, C. S. (2015). Climate Resilient intercropping systems for rainfed black soils of Andhra Pradesh and Maharashtra . *Indian Journal of Dryland Agricultural Research & Development,* **30(1):** 35-41.

Sahoo, U., Malik, G. C., Maitra, S., Banerjee, M., Masina, S., Nath, S. and Suvadra, J. S. (2024). Intercropping system: A climate-smart approach for sustaining food security. *Journal of Applied Biology & Biotechnology,* **12(4):** 30- 36.

Singh, B., Aulakh, C. S. and Walia, S. S. (2019). Productivity and Water use of Organic Wheat–Chickpea Intercropping System under Limited Moisture Conditions in Northwest India. *Renew Agric Food Syst.,* **34(2):** 134–143.

Singh, L., Beg, M. K. A., Akhter, S., Qayoom, S., Lone, B. A. and Singh, P. (2014). Efficient techniques to increase water use efficiency under rainfed eco-systems. *J. Agri. Search,* **1(4):** 193–200.

Shekar, K., Laxminarayana, P., Prashanth, P. and Didal, V. (2019). Climate Resilient Agronomic Innovations for Rainfed Farming in Sub Tropics. *Journal of Pharmacognosy and Phytochemistry,* **SP2:** 152-154.

Toker, P., Canci, H., Turhan, I., Isci, A., Scherzinger, M., Kordrostami, M. and Yol, E. 2024. The advantages of intercropping to improve productivity in food and forage production : A review. *Plant Production Science,* **27(3):** 155–169.

Wallace, J. S., Jackson, N. A. and Ong. C. K. (1999). Modelling soil evaporation in an agroforestry system in Kenya. *Agric. For. Meteorol.,* **94:** 189–202.

Ward, B., Roe, B. E. and Batte M. T. (2016). Potential profitability of strip intercropping with corn and soybeans. *J. ASFMRA.* 149–166.

Xu, Z., Li, C., Zhang, C., Yu, Y., Van der Werf, W. and Zhang. F. (2020). Intercropping maize and soybean increases efficiency of land and fertilizer nitrogen use; a meta-analysis. *Field Crops Res.b* **246:** 107661.

Yang, C. H., Huang, G. B., Chai, Q. and Luo, Z. Z. (2011). Water Use and Yield of Wheat/Maize Intercropping under Alternate Irrigation in the Oasis field of Northwest China *Field Crops Res*., **124 (3):** 426-432.

Yin, W., Chai, Q., Guo, Y., Feng, F., Zhao, C., Yu, A., Liu, C., Fan, Z., Hu, F. and Chen, G. (2017). Reducing Carbon Emissions and Enhancing Crop Productivity through Strip Intercropping with Improved Agricultural Practices in an Arid Area. *Journal of Cleaner Production,* **166:** 197- 208.

Yin, W., Chai, Q., Yu, A., Fan, Z., Hu, F., Guo, Y. and Coulter, J. A. (2020). Water utilization in intercropping: A review. *Agriculture Water Management,* **241:** 106335.

Yin, W., Chai, Q., Zhao, C., Yu, A., Fan, Z., Hu, F. and Coulter. J. A. (2020). Water utilization in intercropping: A review. Agric. *Water Manage,* **241:** 106335.

Zuo, Y., Zhang, F., Li, X. and Cao. Y. (2000). Studies on the improvement in iron nutrition of peanut by intercropping with maize on a calcareous soil. *Plant Soil.,* **220:** 13–25.

Abbreviations

CO_2 – Carbon dioxide
EUE- Energy Use Efficiency
GHG- Green House Gas
K- Potassium
Kg- Kilogram
N- Nitrogen
OM- Organic Matter
P- Phosphorus
t- Tonnes
WUE- Water Use Efficiency