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Enhancing the Green Gram Production by Leveraging New Dimensions of Land and Water Resources Management Technologies: A Comprehensive Review

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ABSTRACT

This review paper explores empirical shreds of evidence across the world on cutting-edge technologies like micro-irrigation, fertigation and mulching, all of which contribute to increased yields while conserving water and improving soil quality. Furthermore, the review highlights the potential of IoT-based irrigation and fertigation automation in reducing waste and labor expenses. By advocating for the integration of these practices, the paper underscores the importance of achieving water-saving objectives, boosting economic returns and ensuring food security. Researchers, policymakers and practitioners committed to sustainable green gram cultivation will find this comprehensive review a valuable resource for implementing innovative and efficient farming techniques.

Key words: Fertigation, Green gram, Micro irrigation, Mulches, Water use efficiency.

The Government of India aims to elevate the nation's economy from its current $3.29 trillion to $5 trillion by 2026-27. Within this vision, the agricultural sector's contribution will have to be surged from $0.66 trillion to $1 trillion, propelled by technological advancements (https://www.downtoearth.org.in/news/agriculture/). In 2022-23, India anticipated a remarkable food grain production of 330.5 million tonnes, a 15 million-tonne increase over the previous year. National targets for 2023-24 included 332 million tonnes of food grains, 27.81 million tonnes of pulses and 44 million tonnes of oilseeds (https://www. down toearth.org.in/news/agriculture/). Additionally, horticulture production for 2022-23 was projected to reach a record 351 million tonnes (https://www.thehindubusinessline. com/economy/).

Climate change stands as the foremost challenge to achieving these objectives, a challenge of immense magnitude. The documented impacts of a warming climate on the hydrological cycle, encompassing heightened evaporation and rainfall, have been comprehensively explored by Rank *et al.* (2020; 2022a; 2023b). Despite the concurrent increase in CO_2 levels, climate change manifests both direct and indirect adverse repercussions on agriculture, water security and food security, as substantiated by Rank *et al.* (2022b; 2022c; 2023a).

To surmount this, judicious management of limited land and water resources within the agricultural sector is imperative, given its substantial water consumption (Patel and Rank, 2022; Rank and Satasiya, 2022). Enhancing agricultural production necessitates augmenting crop acreage and yield, yet the mounting stress from competing sectors makes more land and water allocation unfeasible. Consequently, the focus shifts to enhancing water productivity across all domains. Concentrated efforts on precise irrigation and fertigation management, alongside soil quality enhancements, are paramount to achieving this goal. These objectives hinge on the implementation of diverse technological interventions in land and water management strategies, well-documented by some authors (Rank *et al.,* 2019; 2022a; 2022b; 2022c, Rank and Vishnu, 2021a; 2021b; 2023 and Rank and Satasiya, 2022). An approximately 50% surge in water demand by 2025 can be met by enhancing irrigation efficiency. The review survey conducted by Kurdekar *et al.* (2023) on optimizing water inputs for bolstering pulse production recommends strategies such as drip irrigation, fertigation, mulching, rainwater harvesting and optimal irrigation scheduling with drought-resistant crop varieties.

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The global green gram cultivation spans approximately 7.3 million hectares, with an average yield of 721 kg per hectare. India, the leading producer of green gram globally, contributes over 70% of the total production, ranking as the third-highest cultivated pulse crop in India, following chickpea and pigeon pea (Tamang *et al.,* 2015). Green gram thrives across various Indian states, including Orissa, Maharashtra, Andhra Pradesh, Madhya Pradesh, Rajasthan, Bihar and Gujarat. In the 2022-23 season, green gram production reached an estimated 3.74 million tonnes, constituting 11% of total pulse production (Anonymous, 2023). During 2023-24, approximately 1.66 million hectares in India were dedicated to green gram cultivation, compared to 1.56 million hectares in the previous year. However, despite its significance, green gram's productivity in India remains relatively low, with pulse availability per capita falling short of the ICMR recommendation of 80 grams per day in 2022 (https://www.statista.com/statistics/980339/). This underscores the urgent need to enhance green gram productivity to meet the escalating pulse demands of the growing population.

Green gram, also known as mung bean (*Vigna radiata*), holds paramount importance both as a nutritional powerhouse and a soil-enriching crop. Rich in protein, dietary fiber, vitamins and minerals, it plays a vital role in balanced diets, particularly in vegetarian and vegan cultures (Yi-Shen *et al.,* 2018). Beyond its nutritional merits, green gram possesses the remarkable capability to fix atmospheric nitrogen in the soil (Senaratne *et al.,* 1995). Through a symbiotic relationship with rhizobia bacteria, green gram converts atmospheric nitrogen into a usable form, enriching the soil with this essential nutrient. This natural nitrogen fixation not only benefits green gram but also enhances soil fertility for subsequent crops in rotation systems (Senaratne *et al.,* 1995). Additionally, green gram's low fertilizer requirements contribute to sustainable agriculture practices by minimizing nutrient runoff, reducing environmental pollution and conserving resources. Thus, green gram not only promotes human health but also plays a pivotal role in fostering resilient and eco-friendly agricultural systems.

To bolster green gram production with higher water use efficiency (WUE), embracing innovative land and water resource management technologies such as efficient irrigation systems, fertilization, mulching, pulse irrigation and IoT-based automated irrigation and fertigation is imperative (Rajanna *et al.,* 2018; Kurdekar *et al.,* 2023). The subsequent sections of this paper delve into empirical evidence regarding the response of green gram crop performance to these modern land and water resource management paradigms.

Irrigation water management

Drip irrigation represents a transformative breakthrough in agriculture, offering numerous benefits including water conservation (Robert *et al.,* 2022), improved soil health (Patil *et al.,* 2022) and increased crop yields (Ray *et al.,* 2023). By precisely delivering water to plant root zones, drip irrigation minimizes wastage from evaporation, deep percolation and runoff, particularly crucial in water-scarce regions (Mmolawa and Or, 2000). The water productivity can be maximized at optimal water inputs. This concept holds significant importance as yield rises with increasing water supply, but beyond certain thresholds, excessive vegetative growth may lead to a decrease in efficiency (Buttar, 2014; Ray *et al.,* 2023).

Strategies to increase crop water use efficiency include achieving higher yields or conserving water. The deficit irrigation during certain stage of the crops help to enhance yield and save water. Research findings suggest that alternate furrow irrigation and deficit irrigation are effective methods to boost water use efficiency (Webber *et al.,* 2006, Singh *et al.,* 2014; Ray *et al.,* 2023), with green gram benefiting from at least two irrigations (Malik *et al.,* 2006). Drawing from empirical observations, Idnani and Singh (2008) recommended applying 3 irrigations during the branching, pre-flowering and pod filling stages for summer green gram cultivation using furrow planting and irrigation methods. This approach yielded higher productivity, enhanced nutrient uptake, water conservation and improved economic returns on sandy loam soil in Delhi. It's worth noting that in their study, 2 irrigations resulted in higher WUE (43.82 kg/ha-cm) than 3 irrigations (43.03 kg/ha-cm). The maximum grain yield (14.46 q/ha), harvest index (24.94%) and net return (Rs. 44,898) were achieved when irrigation was scheduled at 1.0 PEF (Pan Evaporation fraction).

The irrigation frequency keeping the same seasonal irrigation depth also plays a great role for enhancing green gram crop yield. Chaudhary *et al.* (2014) found that scheduling irrigation at critical growth stages yielded the highest water use efficiency. Yadav and Singh (2014a) conducted a study evaluating the impact of different irrigation scheduling scenarios (1, 2, 3 and 4 irrigations) on the WUE of summer green gram and their findings revealed a decrease in WUE as the number of irrigations increased. The highest WUE (1.94 kg/ha/mm) was achieved when a single irrigation was applied 25 days after sowing. Similarly, Kaur (2014) compared various irrigation schedules, highlighting that treatment at 1.2 PEF yielded the highest green gram production, outperforming other PEF levels but the irrigation schedule at 0.6 PEF demonstrated superior water productivity. In a field experiment conducted by Yadav and Singh (2014b) during the winter months on silty loam soils in UP, India, the impact of irrigation schedules of 0.6, 0.8 and 1.0 PEF at 10-day interval on the WUE of green gram was assessed. The findings indicated a decline in WUE as the level of irrigation increased. The highest WUE (49.12 kg/ha-cm) was reported for the irrigation treatment with a PEF of 0.6 outperforming other treatments. However, the highest values for leaf area index (3.77), yield (14.46 q/ha), harvest index (26.03%), net return (Rs. 43,592) and benefit-cost ratio (3.37) were observed with the 1.0 PEF treatment.

The irrigation intervals also significantly influence green gram production while maintaining the same total seasonal irrigation volume. Ahmad *et al.* (2015) investigated the impact of irrigation interval on WUE of green gram in Saudi Arabia's sandy clay loam soils and revealed that the highest WUE occurred with a 9-day irrigation interval and an irrigation volume of 4000 m^3/ha, employing a total of 10 irrigations. Interestingly, Chaudhary *et al.* (2015) found that the highest seed yield was achieved when green gram was sown with 30 cm × 10 cm spacing and irrigated according to a 1.0 PEF schedule, while the highest net returns and benefit-cost ratio were observed with 0.8 PEF for the same plant spacing. Similarly, Ati *et al.* (2016) reported that irrigating green gram at 25% soil moisture depletion, compared to a control treatment with 50% depletion, resulted in the highest WUE of 2.94 kg/ha-mm for both seasons. Kumar *et al.* (2016) determined that irrigation scheduled at 0.4 PEF yielded the highest WUE, with 5 cm irrigation depth outperforming 8 cm. Praharaj *et al.* (2016) noted that sprinkler irrigation saved water (19.5%) and improved WUE (19.1%) compared to flood irrigation. Ram *et al.* (2016a) reported that delaying the last irrigation to 60 DAS significantly improved WUE. Ram *et al.* (2016b) found the highest WUE with three irrigations applied at 25, 40 and 50 DAS.

Water quality significantly affects pulse growth, with judicious use of poor and good quality water yielding positive results. In their study, Kaur *et al.* (2016) discovered that pre-sowing irrigation with canal water, followed by complete irrigations with poor-quality water (Tube well water; RSC 6.4 meq/L and EC 2200 µmhos/cm), yielded equivalent grain yields in green gram as irrigations solely with canal water. Kumar *et al.* (2016) found that drip irrigation at 2-day intervals with polythene mulch improved both yield and water productivity of green gram in the Indian hill region and eastern plateau. Kaur *et al.* (2017b) evaluated 3 irrigation levels (1, 2 and 3 irrigations in crop cycle) in green gram. The highest green gram yield occurred at 3 irrigations, at par with 2 irrigations. Notably, only 1 irrigation achieved the highest water expense efficiency (WEE), while the lowest WEE at 3 irrigations. Kaur *et al.* (2018) also found that green gram required fewer irrigations (1-2) leading to lower WEE ac compared to cotton and cluster bean.

Patel *et al.* (2020) observed that irrigating green gram at branching, flowering and pod development stages resulted in increased growth and yield. Patil and Tiwari (2021) conducted a 3-year experiment in Kharagpur, comparing green gram crop responses under subsurface drip, conventional furrow irrigation, raised beds with and without plastic mulch and conventional ridge-and-furrow systems. Yields were notably higher with raised beds and plastic mulch, while WUE and N-uptake also improved. Shree *et al.* (2021) studied green gram's response to different drip irrigation intervals and found that 5-day intervals yielded significantly better growth, WUE and yield. Vinoth *et al.* (2022) explored green gram growth and yield in summer under various irrigation methods and found that drip and sprinkler systems showed substantial improvements in seed yield and haulm yield compared to surface irrigation, providing notable benefits for summer green gram crops. In a humid sub-tropical Indian climate, Halder *et al.* (2022) conducted field experiments to optimize irrigation and boron (B) application for green gram. They tested 3 irrigation frequencies (I1 = branching, I2 = branching + flower initiation, I3 = branching + flower initiation + pod development) and recommended to irrigate at branching, flower initiation and pod development stages for optimal summer green gram growth, yield, nutrient content and economic returns.

Ray *et al.* (2023) conducted an extensive review on water productivity in major pulses, including green gram, emphasizing the challenge of insufficient irrigation water in pulse production. They highlighted the importance of efficient water management strategies such as micro-irrigation, stage-specific irrigation, resource conservation techniques, bed planting and mulching. Micro-irrigation can boost yield and water productivity by 31% and 43%, respectively. Encouraging deficit irrigation in arid and semi-arid regions can increase water productivity by 24%. Ridge planting can enhance water productivity by 22% and mulching practices can improve yield by up to 9%. Adopting these practices not only enhances pulse productivity but also promotes natural nitrogen fixation for improved soil health. Verma *et al.* (2023) noted that only two variables, fertilizer and irrigation water, were positively significant in green gram production.

Soil fertility enhancement

Green gram, with its short growth duration and nitrogen-fixing ability, plays a vital role in soil fertility enhancement. Green gram can be cultivated as a mixed crop, intercrop, or in crop rotation or sequence to boost soil nitrogen levels and disrupt disease or pest cycles (Ranawake *et al.,* 2011). Effective soil nutrient management is crucial for crop yield and soil health (Patel *et al.,* 2019). *Kharif*-season green gram cultivation enhances organic content, available nitrogen, phosphorus and potassium levels compared to cotton (Kaur *et al.,* 2017b). Intercropped green gram fixes 197 mg N/plant, obtaining 78% of their N content from the atmosphere (Senaratne *et al.,* 1995). Pulses, like green gram, fix atmospheric nitrogen (30-50 kg/ha) and serve as natural fertilizer factories (Makwana *et al.,* 2020). Integrating legumes into cropping sequences improves soil conditions, resulting in higher yields for subsequent crops like wheat, barley and mustard, which have shown yield increases of 12.8%, 9.4% and 3.3%, respectively, compared to cotton (Kaur *et al.,* 2017a and Kaur *et al.,* 2018).

Fertigation management

Green gram, a legume crop requiring minimal fertilizer doses (Tamang *et al.,* 2015; Verma *et al.,* 2017), often faces yield limitations under rainfed conditions, which fall short of global population needs. Fertigation, combining small,

frequent applications of liquid or water-soluble fertilizers with irrigation, holds promise in boosting green gram yields while mitigating environmental concerns. Fertigation's direct delivery of nutrients to the root zone in an accessible form reduces overall fertilizer application rates (40-60%) and significantly enhances fertilizer use efficiency (Keng *et al.,* 1979; Sandal and Kapur, 2015).

Selvi *et al.* (2004) demonstrated that micro sprinkler-based fertigation during flowering and 15 days afterward significantly improved green gram growth, yield, chlorophyll accumulation and nutrient uptake, with DAP+NM being the most effective treatment. Malik *et al.* (2006) found that applying 40 kg P_2O_5/ha had a positive impact on green gram, with WSF also suitable as foliar sprays for immediate nutrient correction. Fertigation, as compared to conventional methods, resulted in substantial fertilizer savings (40%) without compromising crop yields as reviewed by Sathya *et al.* (2008). Jat *et al.* (2012) recommended a comprehensive approach for cultivating green gram, including raised bed cultivation, FYM application at 5 t/ha and 100% recommended dose of nitrogen (20 kg/ha) and phosphorus (40 kg P_2O_5/ha) doses using saline water for higher yields, WUE, nutrient uptake, improved soil fertility and enhanced economics. Empirical evidence consistently highlights the advantages of fertigation in achieving fertilizer savings of 25-40%, offering significant economic benefits while mitigating nutrient leaching (Sandal and Kapoor, 2015).

The choice of fertilizer source also influences green gram performance. Shree *et al.* (2021) studied the crop's response to fertigation at 5-day intervals using various phosphorus sources. Fertigation with phosphoric acid demonstrated significantly higher yield attributes, seed yield (814 kg/ha) and haulm yield (1745 kg/ha) compared to soil application of SSP and DAP, while being comparable to fertigation of MAP under sodic soil conditions. Chahal *et al.* (2022) found that press mud + fertilizer application outperformed other fertilizer combinations, emphasizing its superior effectiveness. The economic viability of fertigation is subject to consideration due to expensive water-soluble or liquid fertilizers (Rank *et al.,* 2022b). Jata *et al.* (2019) conducted an investigation in Bhubaneswar, revealing that the benefits of fertigation treatments over soil application were significant up to a fertigation level of 80 N kg/a and 80 K_2O kg/ha for green gram cultivation. In addition, combining Rhizobium-Liquid Biofertilizer (LB) and Phosphate-Solubilizing Bacteria (LB) with drip fertigation for green gram crops led to increased NPK uptake and a remarkable 23.93% yield increase compared to conventional methods (Shravani *et al.,* 2019a; 2019b and 2019c).

The promotion of biofertilizers offers a sustainable approach to reducing the reliance on imported fertilizers while curbing soil, water and environmental pollution. Drip fertigation provides an efficient means of applying soluble biofertilizers. Shravani *et al.* (2019a) assessed the efficacy of liquid biofertilizers, specifically Rhizobium and PSB, through various application methods (seed treatment, soil and drip fertigation) for green gram. Combining biofertilizers with inorganic fertilizers notably influenced nutrient levels and soil microbial biomass carbon, achieving the highest organic carbon, N, P, K content and microbial biomass carbon when applying 100% RDF through drip fertigation with liquid Rhizobium and PSB biofertigation. Naik *et al.* (2023) explored the impact of bio-fermented products administered through drip fertigation on green gram at Coimbatore. Among the 13 treatments, the fermented fish waste (FFW) and egg products, particularly with 125% RDF +100% PEF drip fertigation, demonstrated enhanced growth, physiological parameters, yield attributes and overall yield.

Mulching

Mulching in crop cultivation involves covering the soil around plants with organic or synthetic material, broadly categorized as Organic mulch and Synthetic mulch. Bothe mulch types help dace water through soil moisture conservation, control weeds, regulate soil temperature, improve soil health, conserve soil, control pest and diseases *etc*. In fact, organic mulch also enhances soil fertility. Choosing between organic and synthetic mulch should consider specific cultivation goals and environmental factors.

Moisture conservation

Mulch, as supported by research evidences (Singh *et al.,* 1981; Mohammad *et al.,* 2010; Bunna *et al.,* 2011; Ji *et al.,* 2011; Ram *et al.,* 2016b; Kaur and Bons, 2017; Jabran, 2019; Ngosong *et al.,* 2019; Sekhon *et al.,* 2020; Balkrishna *et al.,* 2021; Kaur *et al.,* 2021; Patil and Tiwari, 2021 and Robert *et al.,* 2022) plays a pivotal role in preserving soil moisture, reducing evaporation and ensuring a consistent water supply for plant roots. Singh *et al.* (1981) demonstrated that straw mulch significantly enhances WUE in spring green gram on sandy loam soils. Mohammad *et al.* (2010) stressed the impact of residue retention on WUE, with no-tillage and residue retention yielding the highest crop production efficiency. Bunna *et al.* (2011) reported increased WUE with straw mulch while Ji *et al.* (2011) confirmed plastic film mulch's effectiveness in enhancing WUE.

Chavan *et al.* (2014) found that the application of wheat straw mulch with irrigation at 0.8 IW/CPE to summer green gram significantly increased yields and net returns. Ram *et al.* (2016b) found that straw mulching at 25 days after sowing resulted in the highest yield and maximum WUE. Sekhon *et al.* (2020) highlighted plastic mulch's superior WEE compared to no mulch conditions. Patil and Tiwari (2021) emphasized the reduction in crop evapotranspiration achieved by plastic mulch. These findings collectively underscore the significance of mulching practices in promoting sustainability and optimizing water resources across various growth stages and conditions in agriculture. Kaur *et al.* (2021) also revealed that straw mulch

significantly increased green gram seed yield while conserving water. In a study by Robert *et al.* (2022), mulch significantly enhanced green gram yield. The furrow-ridge mulch treatment with 3 t/ha showed the best yields. This method, along with zero tillage and mulch, proved highly effective for improving green gram yields in Kenyan region, particularly in areas with limited rainfall. Hakim *et al.* (2022) also reported that mulch positively impacted growth, yield and yield components by conserving soil moisture. Furrow-ridge and zero tillage with mulch were found to be the most efficient techniques for achieving better green gram yields (Hakim *et al.,* 2022). Morya and Kushwaha (2022) noted that straw mulch (4 t/ha) led to the highest biomass productivity of green gram (3633 kg/ha) due to reduced soil surface evaporation.

Weed suppression

Severe weed infestation can cause yield losses of 30 to 80 percent in green gram (Algotar *et al.,* 2015). Mulch serves as an effective weed growth barrier, demonstrated in experiments by Sharma and Bhardwaj (2017), Kaur and Bons (2017) and Patil *et al.* (2022). Herbicide-resistant weeds and environmental concerns associated with herbicide use necessitate non-chemical weed control methods (Jabran, 2019). Straw mulching is a successful practice for weed management, offering an eco-friendly alternative to herbicides (Morya *et al.,* 2016). While various plastic mulches, especially black plastic, have been effective (Jabran, 2019; Patil *et al.,* 2022) but environmental concerns have sparked interest in biodegradable alternatives (Carrubba and Militello, 2013, Patil *et al.,* 2022). In fact, research funding is crucial for development of biodegradable plastic. Straw mulches show promise for weed control, with efficacy varying in different situations. Paper mulches have also succeeded in various crops and organic waste-based mulches hold potential for weed suppression when used correctly (Sharma and Bhardwaj, 2017). Verma *et al.* (2017) recommended combining mulching and herbicides for effective weed management and optimal green gram yields in agri-horticultural systems. Additionally, non-chemical control methods, such as straw mulch, can reduce weed biomass in green gram crops by 12-63% (Singh and Singh, 2020).

Temperature regulation

Soil temperature fluctuations, exacerbated by climate change, can harm both plants and soil ecosystems. Soil mulching helps mitigate these temperature swings, benefiting plants and soil microbial growth. Careful selection and application of mulch are crucial to avoid potential drawbacks (Jabran, 2019). Optimizing mulch type, timing and quantity can protect soil, plants and soil organisms from temperature extremes and contribute to sustainable cultivation practices. These findings were reflected in various studies by Aniekwe *et al.* (2004); Sharma and Bhardwaj (2017) and Kaur *et al.* (2021). Sharma and Bhardwaj (2017) emphasized the use of mulch paper for effective temperature regulation.

Soil health improvement

Intensive farming practices can negatively impact soil health, but incorporating organic mulches such as leaf litter, plant debris and compost can significantly foster the growth of earthworms, termites, fungi, bacteria and various other soil organisms, thereby enhancing nutrient cycling, increasing nutrient availability and bolstering organic matter content. These biological communities also produce enzymes that aid in soil rehabilitation and nutrient availability (Jabran, 2019). Organic mulch materials naturally decompose over time, enriching the soil with valuable organic matter. This decomposition process improves soil structure, fertility and microbial activity, leading to enhanced plant nutrient uptake (Bhardwaj, 2013; Kaur and Bons, 2017). Additionally, organic mulches positively influence the physical, chemical and biological aspects of soil by proviing essential nutrients (Dilipkumar *et al.,* 1990; Bhardwaj, 2013, Patil *et al.,* 2022). Moreover, applications of organic mulches like eucalyptus leaves also play a vital role in remedying soil contaminated with heavy metals, reducing potential risks to both animals and humans, as indicated by Salim and El-Halawa (2002). Additionally, intercropping with dual-purpose legumes like cowpea and green gram, especially when planted alongside spring cane, can enhance soil microbial biomass nitrogen, harness allelopathic effects and promote overall soil health, as supported by Shukla *et al.* (2022).

Mulches for nutrient addition to soil

Straw mulches enhance soil fertility by increasing organic carbon content, promoting enzymatic activity and elevating soil organic matter levels (Jabran, 2019). Additionally, they concentrate and enhance nutrient availability. In contrast, plastic mulch, while not directly supplying nutrients, benefits crops by improving nutrient availability and accessibility through better regulation of soil moisture and temperature. The decomposition of organic residues beneath plastic mulch releases organic acids into the soil, reducing pH and potentially increasing the bioavailability of essential micronutrients such as manganese (Mn), zinc (Zn), copper (Cu) and iron (Fe). This is supported by observed increases in Fe and Zn levels in soil beneath plastic mulch (Jabran, 2019). Over time, organic nitrogen mineralizes, leading to higher mineral N (nitrate, NO_3 and ammonium, $NH4^+$) levels in the soil, thereby enhancing nitrogen availability (Jabran, 2019). Plastic mulch also contributes to the breakdown of organic matter, releasing soluble nutrients like NO_3, $NH4^+$, Ca^{2+}, Mg^{2+}, K^+ and fulvic acid into the soil, ultimately increasing overall soil nutrient availability (Patil *et al.,* 2022).

Soil conservation

Mulches play a vital role in combatting soil erosion by forming a protective layer over the soil surface. This layer shields the soil from the erosive impacts of rainfall and

reduces the movement of soil particles caused by flowing water, thus preserving soil structure and preventing topsoil loss (Montgomery, 2007; Kaur and Bons, 2017). Moreover, mulches enhance erosion reduction by increasing soil infiltration, retaining surface water flow and diminishing the erosive force of water (Lal, 2001). Implementing mulching techniques as part of comprehensive land management strategies is essential to mitigate the adverse effects of soil erosion and maintain healthy, productive soils for sustainable agriculture.

Disease and pest control

The growing demand for organic food production and concerns about environmental pollution due to synthetic insecticides and fungicides underscore the necessity for non-chemical approaches to pest and disease control (Jabran, 2019). Mulches have emerged as a promising solution. For example, straw mulch indirectly manages insect pests by providing a habitat for natural predators, increasing pest predation. Colored plastic mulches disrupt insect behavior by altering light spectra, acting as a deterrent, especially in high-value crops. Organic mulches enhance biocontrol agent activity and boost enzyme concentrations, including cellulase, which dissolves pathogen cell walls. Additionally, mulches positively affect soil properties, fostering disease-suppressing characteristics. Some mulch materials can also deter or inhibit certain plant diseases and pests, such as nematodes and pathogenic soil fungi (Johnson *et al.,* 1979; Kaur and Bons, 2017). Johnson *et al.* (1979) mentioned that conventional rate of DD-MENCS (376 kg/ha) could be reduced by 43% by adopting film mulch with trickle irrigation and a more efficient control for nematode and fungi management.

In conclusion, mulching serves as a crucial intermediary between the soil and atmosphere, offering numerous benefits, including moisture conservation, soil temperature moderation, microclimate modification, improved soil physical, chemical and biological properties, weed suppression and erosion prevention (Kaur and Bons, 2017).

In a comprehensive review, Kaur and Kaur (2023) conducted a detailed survey of interventions such as micro-irrigation, mulching and fertigation aimed at enhancing the WUE of the green gram crop. The review highlights that these interventions, encompassing irrigation, fertilization and mulching, collectively exert a positive influence on enhancing the WUE of green gram cultivation.

Negative impacts of mulching on pollutions of soil and environment

organic and plastic/synthetic mulches have distinct effects on the environment and soil pollution. organic mulches, derived from plant or animal materials, decompose over time, enriching the soil with organic matter and nutrients, which enhances soil health and structure (Iqbal *et al.,* 2020). However, the decomposition process can also release greenhouse gases like methane and nitrous oxide, contributing to climate change (Erenstein, 2002). In contrast, plastic mulches are highly effective in weed control and moisture retention but organic and plastic/synthetic mulches have distinct impacts on environmental pollution and soil health. Organic mulches, such as straw, wood chips and compost, improve soil structure and fertility as they decompose, adding essential nutrients and organic matter (Iqbal *et al.,* 2020). This decomposition process can enhance microbial activity and soil biodiversity, leading to healthier and more resilient soil ecosystems (Erenstein, 2002). However, the decomposition of organic mulches can also release greenhouse gases like methane and nitrous oxide, contributing to climate change (Iqbal *et al.,* 2020). On the other hand, plastic/synthetic mulches, while effective in controlling weeds and conserving soil moisture, pose significant environmental challenges. They are typically made from non-biodegradable materials that contribute to plastic pollution when they degrade into microplastics, contaminating soil and water systems (Farmer *et al.,* 2017). Additionally, the production and disposal of plastic mulches generate carbon emissions and other pollutants, exacerbating environmental degradation (Haapala *et al.,* 2014). Therefore, while both types of mulches offer agronomic benefits, their environmental impacts must be carefully considered to promote sustainable agricultural practices.

Advances in Iot automation of irrigation and fertigation

Smart irrigation systems, utilizing wireless technology and advanced control incorporating soil, plant and weather-based monitoring within predictive models offer a solution to enhance input use efficiency, aiding in the selection of optimal inputs strategies and promoting sustainable practices (Bwambale *et al.,* 2022). For green gram cultivation, implementing IoT-based automation for irrigation, fertigation and chemigation schedules revolutionizes resource optimization. Real-time data from sensors monitoring soil moisture, weather conditions and nutrient requirements enables precise delivery of water, fertilizers or pesticides, reducing waste and enhancing crop health and yield. Reduced manual interventions decrease labor and operational costs, improving overall efficiency and profitability.

Precision agriculture, particularly smart irrigation and fertigation, empowers resource conservation and prevents moisture and nutrient deficits in the root zone (Pierce, 2010). IoT based smart techniques ensure precise resource delivery, considering timing, quantities and location within the field (Singh *et al.,* 2019). IoT integration offers a comprehensive approach, addressing climate change, irrigation inadequacies, soil degradation, nutrient imbalances, plant diseases, security concerns and labor shortages. Uma Maheswari *et al.* (2022) presented a cost-effective IoT solution for automating precision drip irrigation, early disease detection and automated treatments, utilizing sensor nodes, weather APIs and machine learning. Pulse

drip irrigation, a new paradigm, prevents root zone hypoxia in water-sensitive crops like green gram. Intermittent irrigation with fixed on-and-off intervals prevents excess flooding, enhancing crop yields (Madane, 2019). Pulse irrigation conserves water, maintains soil moisture near field capacity and horizontally spreads soil moisture within the root zone, reducing deep percolation losses (Rank and Vishnu, 2021a; Rank and Vishnu, 2021b; Rank and Vishnu, 2023a). Their automated pulse drip irrigation system provides effective control over irrigation, offering a labor saving solution (Rank and Vishnu, 2019). In summary, smart irrigation systems, IoT automation and pulse drip irrigation collectively contribute to resource-efficient, high-yield agriculture, addressing critical challenges in sustainable crop production.

CONCLUSION

The review explores innovative land and water resource management technologies to enhance green gram production in response to global demands for sustainability and water conservation. It covers micro-irrigation, fertigation, deficit irrigation and mulching for water conservation, soil health and pest control, ensuring crop sustainability and soil fertility. Additionally, it discusses IoT-based automation for precise resource management, reducing waste and labor costs, bolstering the economic viability of green gram cultivation. Integrating these practices is crucial for achieving water-saving goals, reducing water footprints and enhancing farmer returns. Leveraging these approaches significantly elevates green gram production, contributing to global food security and sustainable agriculture. This review is a vital resource for advancing efficient green gram cultivation. In fact, the research efforts on the effects of mulching on soil conservation and pest and disease control for the green crop are yet not made in the world anywhere. Therefore, it is suggested to conduct research on it to have the location specific empirical evidences.

Conflict of interest

The authors wish to affirm unequivocally that they have no conflicts of interest to report concerning the review presented in this paper.

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