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INNOVATIVE FARMING METHODS FOR A SUSTAINABLE FUTURE

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ABSTRACT

Global population growth is surpassing food production, with an estimated 9 billion people by 2050. Since land expansion is limited, innovation within existing agricultural systems is crucial. Modern technologies such as drones, AI-based monitoring, automation in planting, weeding, and harvesting can enhance productivity while conserving resources. However, adoption remains low due to high costs, maintenance needs, and limited technical expertise. Government support through subsidies, incentives, and training can accelerate adoption. Embracing such innovations is essential to ensure sustainable food security and revolutionize global agriculture for future generations.

KEYWORDS: Innovation, Smart farming, Soil less cultivation, Sustainable agriculture

INTRODUCTION

Today, agriculture is facing numerous issues on a global scale. By 2050, there will likely be 9.2 billion people on the planet. It goes without saying that a large increase in food production would be required to feed this growing population. To feed this constantly growing population, food production is predicted to need to rise by 70% of current levels (FAO,2011). However, factor productivity is dropping and the amount of land available for agriculture is decreasing. Since about 80% of arable land is now under cultivation, land area growth is not feasible. The principal challenges are climate change, which is leading to many secondary challenges like desertification, increasing disease outbreak, shift in rainfall patterns and increasing extreme weather events which is a threat to future generations and questioning the sustainability of the system. Under this alarming situation a need of the hour is to adopt innovations in farming to increase the pace of production by using highly efficient real-time data based technologies.

A new set of methods known as "innovative farming" is being used in agriculture to boost production, climate resilience, and sustainability.

Many governments are supporting agricultural innovations in response to the need for developing

sustainable agriculture in the face of population expansion, resource scarcity, ecological degradation, and the climate change. To increase the factor productivity, we have to deal with spatial and temporal variabilities by using real time sensors which provide data on soil moisture, temperature, plant health and nutrients. All this is achieved by adopting Precise practices in agriculture like Site Specific Nutrient Management (SSNM). Moreover, to deal with labour shortage, due to increasing rural to urban migrations, can be tackled by use of robotics in agriculture like Drones, automated tractors, weeders and harvesters which will operate the system with high accuracy and speed. Utilising the space through vertical farming is yet another innovative approach to deal with land shrinkage and degradation die to rapid urbanisation. These all practices will provide a paradigm shift in today's agriculture and will decrease the ecological imprint. Despite of such broad applications and benefits it is still not adopted due to high upfront expenses and maintenance cost which can't be afforded by marginal and small-scale farmers. Also, it requires a great manoeuvre to operate such high-tech machineries and AI algorithms. Wide scale adoption is made by policy intervention like training and incentives which can workout the gap.

INNOVATIVE APPROACHES TOWARDS SUSTAINABILITY

This includes various approaches like Precision agriculture, vertical farming, Soil less cultivation, regenerative farming, climate smart agriculture, robotics and automation in farming, bio pesticides and organic alternatives.

1. PRECISION AGRICULTURE

Precision agriculture (PA) is a new and advanced method in which farmers provide optimised-inputs such as water and fertilizers to enhance productivity, quality, and yield (Gebbers & Adamchuk, 2010).
It is a need-based farm management strategy to apply inputs based on the spatial and temporal variability rather than uniform application throughout the field. This is achieved by Site specific management practices based on real time data collected by sensors. These data are collected, stored and analysed with the help of tools like Global Positioning System (GPS), Geological Information System (GIS), Remote sensing and precise application is done by tractor mounted Variable rate applicators.

GPS helps in collection of location specific data and making data maps with the help of GIS which makes these overlapping maps of various attributes like soil health, nutrient distribution, weed spread etc. remote sensing is another tool which use satellite imagery to generate synoptic view of field enabling farmers to

detect disease and infestation at the earliest. It helps in advanced estimation of yield and yield mapping. An integral part of PA is SSNM under which application of nutrients is done by focusing on their indigenous supply and targeted yield. These all prevents the resource wastage by increasing the resource use efficiency thus approaching sustainability

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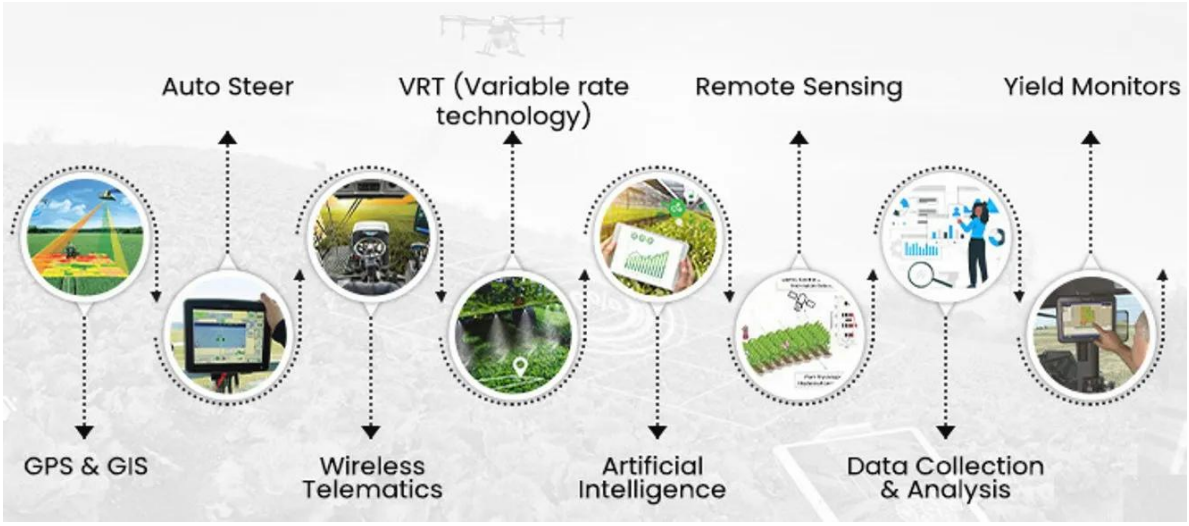

Fig 1: component of precision farming Source: geopard.tech.com

2. VERTICAL FARMING

Due to urbanisation and industrialisation the land has become limited and further expansion is unattainable, but the demand for food, fuel, and fibre is increasing with burgeoning population. This demand can be fulfilled by expanding the land "vertically". It is a Novel concept of growing plants vertically in stacks, under controlled environmental conditions. It incorporates Soil-less techniques along with Controlled Environment Agriculture (CEA), optimising productivity. This will furnish multiple benefits particularly higher water use efficiency, decreasing reliance on soil and at the same time producing quality foods (Barui *et al.*, 2022).

Main techniques used are hydroponics, aeroponics and aquaponics. It helps in saving resources like water, land, labour and time. Vertical rice nursery is an efficient application of this technology which is in use nowadays. The nursery is free from insects, weeds and a smaller number of sick seedlings. These seedlings recover fast in the field and 85% less water is used.

It is used for growing seasonal vegetables like lettuce, mint, basil, tomatoes, and some indoor plants and flowers. It helps in round year food production due to congenial environment without the risk of weather extremities. Moreover, reduces transportation cost by allowing production in consumer's vicinity.

3. SOIL LESS CULTIVATION

It is a cutting-edge technology of growing plants without soil using only nutrient solution. Variants are - Hydroponics, Aeroponics, and Aquaponics.

3.1. Hydroponics: It is a technique of growing plants in a nutrient solution and using inert media (sand, coconut husk etc) to support roots. Roots are submerged in nutrient solution containing required macronutrients and micronutrients. It is a viable system of high-quality food production approaching sustainability. As the water is recycled and used in the system again and again it saves a lot of water and better control of plant nutrition is achieved due to precise control over the delivery system.

3.2. Aeroponics: Despite of submerging in nutrient solution, here the roots are suspended in air and a nutrient rich solution is sprayed over roots giving greater access to oxygen. It promotes healthier plants with vigorous growth and saves 90% of water.

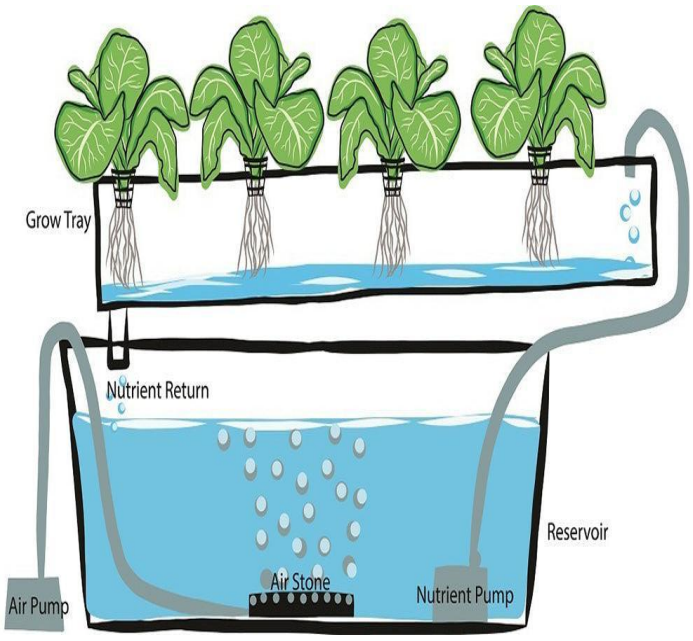

Fig 2: Hydroponic system Source : LetPot.com

3.3. Aquaponics: It is an integrated system of growing plants and cultivating aquatic organisms. It has a water loop in which waste from fish aquarium is filtered and directed towards plants which is utilised for their growth and then plants purify the water before re-directing the fish tank. However, aquaculture is not as widely used as conventional Hydroponics.

4. CLIMATE SMART AGRICULTURE

Due to rapid urbanisation and industrialisation greenhouse gas (GHG) concentration is increasing in atmosphere which is leading to Global warming. In 2022, global agrifood systems were responsible for about 16.2 billion tonnes of CO_2 equivalent emissions, which is roughly 10 percent higher compared to the year 2000 (FAO,2024). Climate Smart Agriculture (CSA) is a strategy to ensure food security and sustainable agricultural development in pace with climate change. Its three pillars are productivity, adaptability and mitigation.

Utilising renewable energy, effective resource management, resource conservation technologies, land use management, etc., can all increase productivity. Adaptation means able to grow under climate change conditions and mitigation is reducing GHG emissions (Abhilash *et al.*, 2021).

Many Land use, crop, soil and water management systems are included in climate smart techniques. Under crop management practices, cultivation of climate resilient and climate smart crops like drought resistant crops which can withstand moisture deprived conditions and give sufficient yields. These novel varieties can be developed by biotechnological methods like CRISPR gene editing and molecular breeding. Managing the land use can also be used to achieve sustainability by afforestation, mulching and agroforestry to sequester carbon and reduce carbon footprint. Water use is managed by using efficient micro irrigation methods such as drip irrigation. Irrigating by drip method saves a lot of water by applying precisely near root zone area as and when needed. Other methods are crop rotations and diversification. These practices would help in feeding population under changing climate scenario (Ma & Rahut, 2024).

5. ROBOTICS AND AUTOMATION IN FARMING

Due to rapid urbanisation and rural to urban migration, there is a rising issue of labour shortage. This along with lack of skilled farmers, are impacting farm productivity and profitability. 'Smart Farming' with the use of Artificial intelligence (AI) will encourage the production. It incorporates the use of drones for precise monitoring and efficient fertilizer application in the farm. These drones, either controlled manually or in auto pilot mode, can spray a large area in short time span saving labour. Rather than eye examining, Smart farming uses sensors to gather data and then data driven decisions are made by using AI tools.

Automation in agriculture includes drones, robots, and automated monitoring systems (Aijaz *et al.*, 2025). Modern agricultural gear, such as autonomous tractors, harvesters, and weeders, may function without direct human involvement.

With the help of advanced technologies like GPS, sensors, cameras, and artificial intelligence, these autonomous robots can perform a wide range of tasks in the field with remarkable precision and effectiveness. Autonomous harvesters help in harvesting crop by identifying the ripen plants-with help of mounted sensors and cameras. Due to advanced technology harvesting is done in short duration minimising post-harvest losses and performed in bad weather conditions also. AI based weeders help out in removing weeds precisely without any harm to crop, encouraging sustainable weed control without using pesticides.

Automation in agriculture has many benefits, such as increased productivity and reduced labour expenses. With the use of sensors, GPS, and artificial intelligence, automated machines can do labour-intensive tasks more rapidly and precisely while requiring fewer human intervention. This leads to continuous field operations and improved resource management because inputs like water and fertilizers are delivered exactly where and when they are needed, removing waste and environmental effects.

6. BIO PESTICIDES AND ORGANIC ALTERNATIVES

Biopesticides are living organisms or products derived from natural sources, like metabolites or natural-identical synthetic sources, that can be used to control pests. They are valuable pest management tools in sustainable agriculture. They protect crops from a wide range of pests and diseases while exhibiting specificity against target organisms and with minimal environmental impact. Incorporation of biopesticides into integrated pest management (IPM) programs provides a more holistic approach for growers to maximise crop yields, reduce over-reliance on chemical pesticides, safeguard agroecosystems, and enhance crop yield and quality. Thus, these nature-based formulation and other organic alternatives like composts, vermicompost, green manure, etc provide soil and plant with balanced nutrition and reduce reliance on synthetic chemicals. Thus, it is a sustainable approach.

7. REGENERATIVE AGRICULTURE

Regenerative agriculture (RA) is where tradition meet innovation not for sustainable but beyond sustainable food production. It is a method of producing food and at the same time restoring the health of soil, plants, animals and whole ecosystem by adopting practices which promotes nutrients and water cycling. It emphasize practices like crop rotation, mulching, minimum tillage, agroforestry, rotational grazing and organic amendments. Unlike conventional agriculture, RA works with natural processes, sequestering carbon in soil and reducing chemical dependence.

FUTURE POTENTIAL

Globally agriculture emits the second most quantity of GHGs and used 70% of freshwater reserves. According to FAO (2016), global predictions shows that agricultural land can only be added by 2% more until 2040. By adopting the above said tools and techniques we can deal with the issues which risks our ability to feed ourselves in future. Even if 20 % of the arable land will be managed by regenerative practices, it will help in sequestering as much carbon to reverse the climate change. Vertical farming will help in utilizing the limited land resources to the fullest and at the same time conserving water. Soil less cultivation will reduce our dependence on the soil thus overcoming the impact of degraded land on the food production. Optimization of the resources through precision agriculture bring down the soil and water pollution and at the same time cut down the cost of inputs, making a win-win situation for both environment and the producer.

CONCLUSION

Innovative farming methods are reshaping the future of agriculture by making it more sustainable, efficient, and resilience. The integration of AI based technologies and data driven approaches is empowering farmers to make smarter, real-time decisions. Precision farming ensures optimal resource use and minimum environmental effects. Vertical farming and soil-less cultivation is breaking the limitations of land-based agriculture offering promising solution for land shrinking. The adoption of bio pesticide promotes healthier ecosystem and reduces chemical reliance. Moreover, Climate-smart agricultural practices are equipping the sector to adapt and mitigate the effect of climate change. Automation and robotics perform humanly tasks with great precision, enhancing productivity and reducing labour constraint. Together, these advancement signals transformative shift towards more sustainable and technologically empowered future in farming.

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