International Journal of Research in Agronomy

E-ISSN: 2618-0618
P-ISSN: 2618-060X

www.agronomyjournals.com
2024; SP-7(10): 693-700
Received: 24-08-2024
Accepted: 02-10-2024

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Embracing smart agriculture: Meeting global food needs and tackling today's farming challenges

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DOI: https://doi.org/10.33545/2618060X.2024.v7.i10Sj.1867

Abstract
Escalating population is the foremost hindering factor of development across the world. World's populace is expected to 2.4 billion upsurges by 2050 and bulk of these will live in major cities of developing countries. To feed the estimated population, the current agricultural production must increase by 60 percent by 2050 to satisfy the expected demands for food if current trends of consumption and economic growth continues. With this mounting target to escalate agricultural production, the present-day agriculture production is in declining trend mainly due to the problems like degradation of soil properties and fertility, soil erosion, shrinking of resources, pollution of resources, supply of spurious inputs, increasing cost of labours, labour scarcity, fragmented landholdings, stagnation and declining trends in productivity and natural calamities due to changing climate. Therefore, agriculture must transform itself to feed escalating worldwide populace and deliver the basis for financial growth and poverty reduction with new technologies, which are capable to take farm productivity and profitability to the next level and to overcome all difficulties in feeding the estimated population. India has demonstrated big transformation in the agriculture sector after 'Green Revolution' but now we need to go for a 'Technology Revolution' to accelerate the progression in the farming sector. This technology revolution is nothing but smart agriculture which has got all hi-tech inputs that can steer us away from the glitches of present-day agriculture. Smart agriculture has the potential to double the food production and reducing wastages and losses by 50 percent by 2050 along with lesser impact on environment. Smart agriculture is the all-new agricultural production mode and ecosystem which is based on digital farming, smart farming, and precision agriculture through use of information and communication tools and technologies.

Keywords: Smart agriculture, food security, contemporary issues in current agriculture, transformation, technology revolution, doubling food production

Introduction

One significant problem impeding global development is population expansion. By 2050, the global population is projected to increase by 2.4 billion from 2015 (Anonymous[1], 2015) [2]. The majority of these extra 2.4 billion people would reside in emerging nations like Nigeria, Bangladesh, Ethiopia, and others like India. Most people will live in cities at the same period (Anonymous[3], 2017,) [4]. According to estimates from the Food and Agriculture Organization, to meet the anticipated demand for food and feed in 2050, agricultural production will need to rise by 60% (Anonymous, 2018) [5]. Therefore, agriculture must change if it is to feed the growing global population and serve as the foundation for economic progress and the eradication of poverty. Therefore, agriculture must change if it is to feed the growing global population and serve as the foundation for economic progress and the eradication of poverty. In addition to these issues, the modern agricultural system is also plagued by several others, including the deterioration of soil fertility and properties, soil erosion, the depletion and pollution of natural resources, the availability of counterfeit inputs, the rising cost of labor and the labor shortage, fragmented landholdings, stagnation and declining productivity trends, and the negative effects of climate change on agriculture and the frequency of natural disasters. Because all of these are impeding the production of food, agriculture must adapt itself with new technologies, which appear to hold great promise for advancing farm productivity and profitability to the next level in order to overcome all challenges and feed the growing population. With the "Green Revolution," India's agricultural sector underwent a significant transition in the second half of the 20th century (Mariani & Kaji, 2016) [16]. However, in order to accelerate this progress, we now need to pursue a 'Technology Revolution' (Anonymous, 2023) [7]. The technology revolution is nothing more than smart agriculture, which by 2050 could increase food production while lowering losses and wastages by 50% and having less of an impact on the environment (Anonymous2, 2017) [10]. Using information and communication tools and technology (IT & ICT), smart agriculture has been continuously advancing on a brand-new agricultural production mode and ecosystem that is built on digital farming, smart farming, and precision agriculture. Considering these current agrarian problems, in this review study an attempt was made to 1. To comprehend the idea of smart farming and smart farming practices, 2. To delineate the smart agricultural practices to feed the growing world population and resolve current agrarian problems from different cases which sets as base for smart agriculture adoption is alternative to overcome the current agrarian problems.

1. Concept of Smart Agriculture (SA) and Smart Agriculture Practices (SAPs)

Smart agriculture has evolved significantly over the past few decades, emerging as a new paradigm for agricultural production that integrates digital farming and precision farming. This approach, known as smart agriculture, represents the third wave of the agricultural revolution, focusing on providing inputs precisely when and where they are needed. To transform Indian agriculture, it must become more productive, utilize inputs more efficiently, produce sustainably, and exhibit greater resilience to risks, shocks, and long-term climate variability. The Food and Agriculture Organization (FAO) identified three pillars of sustainable development of economic, social, and environmental in climate-smart agriculture (CSA) (Anonymous, 2017) [4] & (Anonymous1, 2017,) [10]. The three main pillars are:

- Stable growth in agricultural output and income
- Strengthening resilience to climate change and adaptation
- Reducing or eliminating greenhouse gas emissions where practicable

At the farm level, production systems need to be more effective and resilient to address these interconnected issues. Resource conservation and smart agriculture practices involve using less land, water, and other resources to generate more output.

As agriculture modernizes, terms like smart agriculture, precision agriculture, smart farming, and digital farming have been used interchangeably, though they have subtle differences.

Understanding Key Terms

- **Precision Farming or Precision Agriculture (PA):** Precision farming and precision agriculture are generally regarded as synonymous. Precision agriculture, often abbreviated as PA, is a technology-enabled approach to farming management that observes, measures, and analyzes the needs of individual fields and crops (Anonymous, 2016) [3].
- **Digital Farming:** The essence of digital farming lies in creating value from data. It involves going beyond the mere presence of data to generate actionable intelligence and meaningful added value. Digital farming integrates both precision farming and smart farming concepts.
- **Smart Farming:** Smart farming applies information and data technologies to optimize complex farming systems. Unlike precision agriculture, the focus of smart farming is not solely on precise measurements or determining differences within the field or between individual animals. Instead, it emphasizes access to data and the application of this data to make informed decisions.
- **Smart Agriculture:** Smart agriculture is a broader concept that includes precision agriculture, smart farming, and digital farming. It encompasses various practices that leverage tools, techniques, web applications, mobile apps, GIS, GPS, decision support systems, expert systems, and other data-driven tools to increase agricultural production and productivity while optimizing resource use and minimizing environmental impact.
- **Smart Agriculture Practices (SAPs):** SAPs refer to the diverse practices used in smart agriculture, which may include Tools and techniques, Web applications and mobile apps, Geographic Information Systems (GIS), Global Positioning Systems (GPS), Decision support systems, Expert systems, Implements handling techniques and Other data-driven tools

Market Estimates for Smart Agriculture: The smart agriculture market, valued at USD 13.7 billion in 2020, is projected to reach USD 22.0 billion by 2025, growing at a CAGR of 9.8% during this period. This growth is driven by the increasing global population, the rising adoption of modern technologies in agriculture, and a heightened focus on livestock monitoring and disease detection. Despite a marginal dip in 2020-21 due to the COVID-19 pandemic, which disrupted supply chains and imposed movement restrictions, the market is expected to rebound. The adoption of remote monitoring technology and farm management software tools is anticipated to drive higher adoption rates post-pandemic.

The agriculture sector is on the brink of a revolutionary transformation driven by cutting-edge technologies. As we enter an era of unprecedented innovation, several groundbreaking technologies are set to redefine agricultural practices (Anonymous1, 2023) [12]. These include the Internet of Things (IoT), Artificial Intelligence (AI), Blockchain, Robotics, Autonomous Swarms, Artificial Intelligence of Things (AIoT), and Big Data. The integration of these advanced technologies promises to enhance productivity, efficiency, and sustainability in agriculture, paving the way for a new age of smart farming (Anonymous, 2016) [3]. Given the projected increase in the world's population by 2.4 billion by 2050, the challenge of ensuring food security is more pressing than ever. Current agricultural methods face numerous issues, from soil degradation to the impacts of climate change. This necessitates a transformation in agricultural practices, focusing on efficiency and sustainability. Smart agriculture, through the use of advanced technologies, offers promising solutions to these challenges.

Deliberation of Smart Agricultural Practices to Feed the Burgeoning Global Population and Overcome Current Agricultural Problems

Smart agricultural practices are grouped into various categories based on their application in different stages of agricultural activities. These categories include:

- Precision in Seed Sowing and Planting
- Precision in Nutrient Management
- Efficient Water Management
- Weed and Pest Management
- Resource Conserving SAPs
- SAPs for Higher Productivity & Profitability
- SAPs for Marketing of Agricultural Produce

a) Deliberation of Precision Sowing and Precision Nutrient Management Smart Agricultural Practices

To feed the escalating global population and address contemporary agricultural challenges, various smart agricultural practices (SAPs) have been developed. These practices are crucial for optimizing efficiency in different agricultural activities, including seed sowing and nutrient management.

1. **Precision Seed Sowing and Planting:** Seed sowing at right place, right depth and right amount is very tedious in fields. Effective seeding requires control over two variables: planting seeds at the correct depth and spacing. Utilizing precision seeding equipment that incorporates geo-mapping and sensor data to ensure seeds are planted at the correct depth and spacing. This technology improves seed germination rates and overall productivity. Enhances food production by ensuring better seed placement, which is critical for optimal crop growth. It also addresses labour scarcity and increases accuracy in sowing operations (Zhang *et al*, 2020) [21].
2. **Precision in Nutrient Management:** Site-specific nutrient management (SSNM) is a method designed to optimize the application of nutrients in crop production. By providing crops with nutrients precisely when and where they are needed, SSNM ensures that nutrient demand and supply are balanced. This approach enhances nutrient use efficiency and addresses spatial variability in nutrient availability across different field crops. The systematic nature of SSNM allows farmers to make informed decisions about fertilization and ultimately leading to improved crop yields and sustainable farming practices (Sharma *et al.*, 2020) [17].

a) **Smart Fertilizers:** These fertilizers are formulated with micro-organisms and nano-materials for controlled nutrient release, synchronizing nutrient availability with plant demands. Increases crop yields by 10%, conserves soil health, and can raise farmers' income by 15-20% (Anonymous, 2017) [13].

b) **Leaf Colour Chart:** Leaf colour is a valuable indicator of a plant's nitrogen status. By observing changes in chlorophyll content and leaf colour, farmers can optimize nitrogen use to match crop demand. The leaf colour chart, developed by the International Rice Research Institute in the Philippines, is an effective tool for this purpose. This chart helps farmers determine the right time to apply nitrogen by correlating leaf colour intensity with nitrogen levels in rice plants. A tool that helps farmers assess the nitrogen status of plants by observing changes in leaf color, enabling them to apply nitrogen more precisely. Saves 15-20% nitrogen (Anonymous, 2015) [9], improves profit margins for farmers, and reduces pollution of natural resources.

c) **NDVI Sensors:** Remote sensing technology that measures the Normalized Difference Vegetation Index (NDVI) to determine crop health and nitrogen needs. Saves 15-20% nitrogen without yield penalties, thus improving farmers' profit margins (Singh *et al*., 2015) [19].

d) **SPAD:** SPAD (Soil-Plant Analysis Development) is a simple, quick, and portable diagnostic tool for monitoring leaf nitrogen (N) status and improving the time of N top dressing in rice. SPAD is low-cost chlorophyll meter and affordable by farmers. A low-cost chlorophyll meter that serves as a portable diagnostic tool for monitoring leaf nitrogen status and improving the timing of nitrogen topdressing in rice. Reduces nitrogen losses and leaching, thereby cutting down costs. (Singh *et al*. 2015) [19].

e) **Nutrient Expert:** A decision-support system that provides site-specific nutrient management recommendations by considering yield responses and targeted agronomic efficiencies. Assists farmers in making informed decisions, reduces costs on inputs, and considers nutrients from indigenous sources, thereby improving profit margins (Anonymous, 2017) [14].

f) **Urea Deep Placement:** Urea is compressed into briquettes and placed at a soil depth of 7 to 10 cm to enhance efficiency. Increases yields by 25%, reduces fertilizer costs by 25%, decreases nitrogen losses by 40%, and increases urea efficiency by 50% (Anonymous, 2020) [6].

Table 1: Deliberation of precision sowing and precision nutrient management smart agricultural practices to feed the escalating global population and to overcome contemporary agricultural problems in sowing and nutrient management

SI. No.	SAPs	Key features of SAPs	Contribution to feed escalating population & overcome contemporary agricultural problems
1. Seed Sowing and Planting: Achieving preciseness			
a.	Sowing	Planting seeds at the correct depth, & spacing. Better germination	Enhanced food production Labour scarcity, Accuracy
2. Precision in Nutrient Management			
b.	Smart Fertilizers	Micro-organisms and nano-materials. Controlled-release of nutrient with the plant demands	Increased yields by 10% Soil conservation Farmers' income can be raised by 15-20%
c.	Leaf colour chart	Fairly good indicator of the nitrogen status of plant	Saves 15-20 percent nitrogen. Improved profit margins to farmers. Pollution of natural resources.
d.	NDVI Sensors	Sensors can save 15-20% nitrogen without any penalty in yield.	Saves 15-20 percent nitrogen Improved profit margins to farmers
e.	SPAD	Low-cost chlorophyll meter. Portable diagnostic tool for monitoring leaf nitrogen status and Improving the time of N top dressing in rice	Reduces nitrogen losses and leaching. Cuts down the prices
f.	Nutrient Expert	Decision-support systems for improving crop yields with site-specific nutrient management Fertilizer recommendations by considering yield responses and targeted agronomic efficiencies along with contribution of nutrients from indigenous sources.	Assists in decision making to farmers. Considers nutrients from indigenous sources. Improved profit margins to farmers by cutting costs on inputs.
g.	Urea Deep Placement	Urea is made into 'briquettes' of 1to 3 grams that are placed at 7 to 10cm soil depth	Increases yields by 25%. Reduces cost on fertilizers by 25%. Decreases N losses by 40%. Increases urea efficiency by 50%.

Smart agriculture practices for efficient water management

Water is an essential natural resource, crucial for human survival and sustainable development. However, its availability is decreasing, and the demand for water in the irrigation sector is projected to surpass current levels (Anonymous[1], 2018) [11]. To address this, we face three major challenges: maximizing the efficiency and productivity of available water resources in irrigated areas (More Crop per Drop of Water); enhancing productivity in challenged ecosystems such as rainfed and waterlogged areas; and employing grey water (wastewater) for agricultural production (Anonymous[1], 2014) [8]. Achieving these goals necessitates efficient irrigation management to determine when and how much water is needed by crops. Smart agricultural practices (SAPs) are pivotal in this regard, including the use of smart irrigation systems that leverage sensors and IoT technology to optimize water use, drip irrigation which delivers water directly to plant roots enhancing efficiency, and rainwater harvesting to store and utilize rainwater for irrigation. Soil moisture sensors play a crucial role in monitoring soil moisture levels, preventing over- and under-watering and promoting optimal crop growth. Automated irrigation management systems, utilizing real-time data, further increase irrigation efficiency and save labor and resources. Additionally, grey water reuse systems treat and repurpose household wastewater for irrigation, providing a sustainable water source and reducing the demand for freshwater. Precision irrigation practices apply water based on specific crop needs and field conditions, maximizing water productivity and reducing water stress on crops. These efficient water management practices are essential for meeting the increasing demand for food while conserving water resources, thereby enhancing crop productivity and addressing the challenges of diminishing water availability.

1) **Automation Irrigation System:** Pressurized irrigation systems like sprinkler, drip and subsurface drip irrigation are already prevalent irrigation methods that allow farmers to control when and how much water their crops receive (Anonymous[1] 2014) [8]. By pairing these irrigation systems with increasingly sophisticated IoT-enabled sensors to continuously monitor moisture levels and plant health, farmers will be able to intervene only, when necessary, otherwise allowing the system to operate autonomously. While pressurized systems are not exactly robotic, they could operate completely autonomously. In a smart farm context, relying on data from sensors deployed around the fields perform irrigation as needed.
2) **On-farm Reservoir (OFR):** Rainwater harvesting and efficient water use are inevitable options to sustain rainfed agriculture in future. Different states have initiated special programmes for OFR to ensure the sustainability and to improve livelihoods of people.
3) **Deficit Irrigation Supplies:** Under limited water availability condition, irrigation strategies based on meeting the partial crop water requirements should be adopted for more effective and rational use of water. The adoption of deficit irrigation such as regulated deficit irrigation and controlled late season deficit irrigation are becoming an accepted strategy for water conservation and to reduce the amount of water used for crop production predictive analytics, further allow farmers to analyze real-time data of weather conditions, temperature, soil moisture and plant health (Anonymous, 2014) [1].

According to the Alliance for Water Efficiency, most smart irrigation technologies fall under two classifications:

a) **Sensor-based control:** Sensor-based control systems are a cutting-edge approach to irrigation, using real-time data from sensors placed in fields to monitor various environmental factors like temperature, rainfall, humidity, and soil moisture. This continuous stream of data is analyzed to adjust irrigation schedules automatically. For instance, if the sensors detect low soil moisture and high temperatures, the system will activate to water the crops. Conversely, if there's been enough rainfall, the system will hold off on watering to prevent overwatering. To ensure even greater accuracy, this real-time data is combined with historical weather information. This helps farmers anticipate and prepare for unfavorable conditions, optimizing water use and preventing crop stress. By using sensor-based control systems, farmers can ensure their crops get exactly the right amount of water at the right time, leading to better yields and less wasted resources.
b) **Signal-based control:** On the other hand, signal-based control systems rely on weather updates transmitted via radio, telephone, or web-based applications. Local weather stations send these updates to the irrigation controller, which uses the information to adjust the "evapotranspiration rate" (ET)—a measure of water loss through evaporation and plant transpiration. When the weather update indicates high temperatures and low humidity, the ET rate increases, signaling the irrigation system to provide more water. Conversely, cooler and more humid conditions lead to a lower ET rate, reducing the water needed. Signal-based control systems are flexible and can easily integrate with existing irrigation infrastructure, allowing farmers to make informed decisions based on the latest weather data.

When the weather update indicates high temperatures and low humidity, the ET rate increases, signaling the irrigation system to provide more water. Conversely, cooler and more humid conditions lead to a lower ET rate, reducing the water needed. Signal-based control systems are flexible and can easily integrate with existing irrigation infrastructure, allowing farmers to make informed decisions based on the latest weather data. By using these weather forecasts and real-time updates, farmers can adapt to changing conditions and reduce water wastage. Both sensor-based and signal-based control systems contribute significantly to sustainable agriculture by optimizing water use, improving crop yields, and minimizing environmental impact. Adopting these smart irrigation practices allows farmers to enhance their irrigation management strategies, leading to more resilient and productive farming systems.

Table 2: Deliberation of efficient water management smart agricultural practices to feed the escalating global population and to overcome contemporary agricultural problems

SI. No.	Water management SAPs	Key features of SAPs	Contribution to feed escalating population & overcome contemporary agricultural problems
1. Micro-irrigation: Achieving preciseness			
a.	Sprinkler, drip, and subsurface drip irrigation	Water usage efficiency by 80%, 85% and 90% respectively.	Increase in production through year-round by providing critical irrigations. Increase in fertilizer efficiency. Conservation of natural resources like water
2. Smart irrigation through gadgets (IoT / sensor / signal / mobile)			
b.	Smart irrigation using IoT, sensor based and Signal based control	More than 90% of water usage efficiency	Water conservation, per drop more crop. Need and weather-based irrigation to crops
c.	Mobile based motor controller	Switch on and off the motor simply by sending SMS or missed calls. Informs farmer about dry run and water leakage in pipeline through SMS.	Reduced water consumption by 30 percent. Improving land management decisions with irrigation. Reduces the cost and damages. Can be accessed from any place.

b) **Smart agricultural practices for weed and pest management:** Effective and efficient weed and pest management practices are crucial for overcoming current agricultural challenges and increasing food production. Here are some advanced practices highlighted in Table 3:

1. **New Generation Herbicides**: Recently developed post-emergence herbicides offer selective and effective control of weeds in various field crops. These herbicides are required in very low doses, making them easy to handle and transport. Examples: *Pulses and Oilseeds:* Imazethapyr, fenoxaprop-p-ethyl, cyhalofop-butyl, quizalofop-ethyl, clodinafop-propargyl, *Maize:* Tembotrione, *Rice:* Pyrazosulfuron-ethyl, chlorimuron-ethyl + metsulfuron-methyl and *Wheat:* Clodinafop + metsulfuron-methyl. These herbicides effectively control both broad-leaved and grassy weeds, enhancing crop yields and reducing labor costs.
2. **Herbicide Resistant crops (HRCs):** Herbicide-resistant crops (HRCs) are genetically modified (GM) crops specifically engineered to withstand certain broad-spectrum herbicides. These herbicides are designed to target and eliminate surrounding weeds while leaving the cultivated crops intact. As of now, HRCs make up 83 percent of the total GM crop area worldwide, which equates to just under eight percent of all arable land. Initially, most herbicide-resistant GM crops, including maize, soybean, and cotton, were engineered to be tolerant to glyphosate. However, advancements in genetic engineering have led to the development of GM crops with resistance to additional herbicides, such as 2,4-D, dicamba, glufosinate, sulfonylurea, mesotrione, and isoxaflutole. Allowing the cultivation of herbicide-resistant GM crops could revolutionize weed management in agriculture. If the government of India permits the growth of these crops, it could significantly enhance weed management efficiency, thereby reducing labor costs and improving crop yields (Kapoor, 2020) [15].
3. **Artificial Intelligence and Automation in Weed Management:** Robots designed for weeding are part of a larger vision for the future of agriculture. These multifunctional machines can be equipped with sensors, cameras, and sprayers, enabling them to identify pests and apply insecticides accurately. The same base machine can be adapted for various tasks, enhancing its versatility and efficiency. In future farms, these robots will not operate in isolation. Instead, they will be part of an interconnected network that includes autonomous tractors and other machinery. Through integration with the Internet of Things (IoT), these devices will communicate and coordinate with each other, allowing for seamless and automated farming operations. This interconnected system will enable the entire farm to function autonomously, optimizing resource use, reducing labor costs, and increasing productivity. By leveraging IoT technology, farmers will be able to monitor and control these machines remotely, receiving real-time data on crop health, soil conditions, and pest infestations. This will allow for more precise and timely interventions, improving overall farm management and sustainability (Kapoor, 2020) [15].

Table 3: Deliberation of weed and pest management smart agricultural practices to feed the escalating global population and to overcome contemporary agricultural problems

S.N.	Weed and Pest management SAPs	Key features of SAPs	Contribution to feed escalating population & overcome contemporary agricultural problems
a.	New Generation Herbicides	These herbicides are required in very low doses	Assurance of selective effective control of weeds Reduces costs
b.	Herbicide Resistant crops	Genetically modified (GM) crops engineered to resist specific broad-spectrum herbicides, which kill the surrounding weeds leaving the cultivated crop intact	Potential to improve the production Labour shortage Weed management Reduces chemical pollution Decrease in costs
c.	Artificial intelligence and automation in weed	Robots used for weeding Driver-less machines for weeding	Labour shortage Faster work
d.	Agribot and autonomous swarms	Used for spraying pesticide and foliar spray. Covers large area short span.	Protection of crops and increased production with lesser use of weedicide. Overcomes the labour shortage. Faster work. Reduced / no hazardous effect on farmers health due to chemicals.

c) **Resource conserving smart agriculture practices:** The following explanation highlights several resource-conserving smart agricultural practices that enhance efficiency in the production process, conserve natural resources, and ultimately lead to better incomes for farmers. These innovative practices, including laser land levelling, raised-bed planting, and conservation tillage, are instrumental in optimizing resource use and improving agricultural productivity.

1) **Laser Land Levelling:** Precision land levelling using laser-guided systems is a resource conservation technology that ensures perfectly levelled fields1. This technology offers several benefits, including a yield advantage in both direct-seeded rice (DSR) and transplanted rice (TPR), saving 20-25% of irrigation water, better crop establishment, improved nutrient use efficiency, and uniform irrigation. Recent advancements have shown that laser land levelling can also reduce greenhouse gas emissions by improving input-use efficiency and reducing cultivation time.

2) **Raised-bed Planting:** Raised-bed planting involves growing crops such as wheat, maize, pigeon pea, and horticultural crops in row geometry on raised beds with furrow irrigation arrangements. This method helps save irrigation water by 30-40%, as the furrows act as drainage channels during heavy rains, protecting crops from excess moisture. Raised-bed planting also provides excellent opportunities for intercultural operations and crop diversification, enhancing overall farm productivity.

3) **Conservation Tillage:** Conservation tillage practices, which include zero tillage (no-till), reduced tillage, mulch tillage, ridge tillage, and contour tillage, increase the amount of water that infiltrates into the soil and improve organic matter retention and nutrient cycling. These practices enhance soil properties, making it more resilient and improving soil health. Conservation tillage also helps in timely planting, reduces costs, increases profits, and helps crops adapt to terminal heat stress while reducing environmental footprints. Recent research has shown that conservation tillage promotes soil enzyme activity, leading to increased nutrient accumulation and improved soil health.

4) **Crop Diversification:** Crop diversification remains a fundamental agricultural practice, crucial for providing employment and food security to millions in India. It can be practiced through temporal/horizontal diversification, which involves crop rotation, and spatial/vertical diversification. By substituting less productive or high-input crops with more remunerative and low-input alternatives, farmers can improve soil fertility and sustainability. The traditional rice-wheat cropping system, which contributes significantly to the total food grain production, is now being supplemented with crops such as maize, sugarcane, and cotton. These crops require less water and offer higher returns, thereby enhancing overall system productivity and increasing farmers' incomes.

5) **Integrated Farming System (IFS):** The Integrated Farming System (IFS) is an approach that integrates various resource-saving practices to ensure economic sustainability, ecological renewability, and social acceptability. This system has been particularly successful on small land holdings, ranging from 0.4 to 1.5 hectares. It meets the household food, fodder, feed, and fuel requirements while reducing production costs and increasing profits. Horticultural crops, such as fruits and vegetables, and livestock enterprises, such as dairy and goat farming, are promising components that, when integrated with existing farming systems, significantly enhance income and provide nutritional security. IFS also offers more employment opportunities, regular income, and environmental safety by minimizing the negative impacts of intensive farming.

Table 4: Deliberation of resource conserving smart agricultural practices to enhance productivity and profitability to feed the escalating global population and to overcome contemporary agricultural problems

SI. No.	Resource Conserving SAPs	Key features of SAPs	Contribution to feed burgeoning population & overcome current agricultural problems
a.	Laser land levelling	Better crop establishment Nutrient use efficiency Uniform irrigation	Saving of 20-25% of irrigation water Reduced soil erosion Increased yields
b.	Raised-bed Planting	Better crop growth Irrigation in alternate furrow	Saving irrigation water by 30- 40%.
c.	Conservation agriculture	Helps in conserving the moisture and minimum/no disturbance to soil Natural soil mulching	More food Reduces soil losses Drudgery reduction Additional income Reduced costs
d.	Crop Diversification, IFS & Organic farming	Substitution of heavy inputs requiring crops Make whole system economically viable, ecologically sustainable & renewable, socially acceptable	Enhance the system productivity which leads to increase farmers income. Minimize the negative impacts of intensive farming and improve the environment. Increased profit margins per unit.
e.	Multilayer farming	Growing multiple crops of different heights & depths	Multiple crops in same piece of land Increased productivity through intensification Use of nutrients at different depths
f.	Hydroponics & Vertical farming	Soil less /least soil-based production of crops. More crop in limited space	Optimize plant growth in controlled conditions. Profit to the farmers and environmental safety

6) **Conservation Agriculture (CA):** Conservation Agriculture (CA) focuses on optimizing crop yield, economics, and environmental benefits. This approach involves practices such as minimal soil disturbance, maintaining soil cover, and crop rotation, which improve soil health, increase water infiltration, and enhance organic matter retention. CA promotes sustainable farming by improving soil properties, making it more resilient to erosion and environmental

stresses, and reducing the overall carbon footprint of agriculture.

7) **Organic Farming:** Organic farming in India is experiencing a significant resurgence, driven by growing interest from farmers, entrepreneurs, researchers, policymakers, and consumers. This method avoids synthetic inputs, instead relying on natural processes and materials to enhance soil health, protect the environment, and sustain crop productivity. Organic food products are perceived as safer and more nutritious, fetching premium prices and increasing farmers' incomes. Recognizing the long-term benefits of organic farming, the Government of India has implemented numerous initiatives to promote this practice. With strong support from various stakeholders, the scope of the organic farming movement has expanded considerably, contributing to greater biodiversity, environmental protection, and economic sustainability.

Table 5: Multilayer farming illustration with example of Colocasia, Potato, Leafy Vegetable like coriander and papaya

Crops	Planting time	Germination time	Sowing depth	Maturity time
Colocasia	January	2-3 months	25-30 cm	7-8 months
Potato		20-30 days	10-15 cm	2-3 months
Leafy vegetables		5-8 days	3-6 cm	15-25 days
Papaya		7-8 months for fruit setting	15-20cm	9-11

8) **Multilayer farming:** Multilayer farming is an innovative and integrated agricultural system where 4-5 different types of crops are planted on the same land simultaneously. These crops are selected to mature at different heights and times, which is a form of intercropping that has gained popularity. The concept relies on high-density planting principles, optimizing the use of manure, water, land, and vertical space. Multilayer Farming has got various benefits such as *Efficient Resource Use:* By growing multiple crops with varying heights and maturation times on the same piece of land, farmers can make more efficient use of resources such as manure, water, and land; *Increased Yield:* The high-density planting approach results in higher overall productivity; *Sustainability:* This method promotes sustainability by enhancing soil fertility and reducing the need for chemical inputs and *Economic Viability:* Multilayer farming can lead to diversified income sources for farmers, reducing the risk associated with single-crop dependency. Multilayer farming typically involves a combination of crops that complement each other. For example, a farmer might grow a combination of fruit trees, vegetables, legumes, and herbs in the same plot. Each crop occupies a different vertical space and has different nutrient requirements, making the system highly efficient and productive.

9) **Vertical Farming:** Vertical farming involves growing crops in vertically stacked layers, often within controlled-environment agriculture settings designed to optimize plant growth. This innovative farming method incorporates soilless techniques such as hydroponics, aquaponics, and aeroponics. By utilizing vertical space, vertical farming maximizes land use efficiency and can be implemented in urban areas, reducing transportation costs and carbon emissions. The controlled environment ensures consistent and optimal growing conditions, leading to higher yields and year-round production.

10) **Hydroponics:** Hydroponics is a method of growing plants without soil, using a nutrient-rich water solution instead. This solution contains essential macronutrients like nitrogen, potassium, phosphorus, and calcium nitrate, as well as micronutrients such as manganese and zinc. A 'grow system' regulates the balance of nutrition, humidity, and temperature, ensuring optimal conditions for plant growth. Hydroponics uses significantly less water than traditional soil-based farming and eliminates the need for chemicals and pesticides, resulting in cleaner, higher-yield crops. This method also allows for precise control over nutrient delivery, leading to faster growth rates and healthier plants.

11) **Soil Moisture and pH Meter:** This versatile 3-in-1 soil tester measures soil moisture, pH, and light levels. To use it, simply insert the probe into the soil, leaving about 10mm exposed. Switch to the desired setting to measure moisture, pH, or light, and read the scale. For instance, selecting the MOIST setting will show a scale of 1-3 (red parts) indicating the need for watering, 4-7 (green parts) indicating suitable moisture levels, and 8-10 (blue parts) indicating excessive moisture. This tool helps gardeners and farmers determine the right time to water, adjust soil pH levels, and ensure plants receive adequate light, leading to better overall plant health and growth.

Conclusion

Smart agriculture is a game-changer, offering the potential to greatly boost food production while cutting down on waste. Projections indicate that this approach could ramp up agricultural productivity by 70% by 2050. To tap into this potential, we need to build solid infrastructure in our agricultural institutions, fostering a deep scientific understanding of these technologies. This will help in effectively training farmers to use advanced agricultural technologies and equipment in their daily operations. There’s an urgent call to unify the various institutional resources across the country to enhance resource use efficiency with smart agriculture technologies. Leading technology institutions in India, like the Indian Institutes of Technology (IITs), National Institutes of Technology (NITs), and the Indian Institute of Science (IISc), should join forces with top agricultural institutions such as the Indian Agricultural Research Institute (IARI), Indian Veterinary Research Institute (IVRI), National Dairy Research Institute (NDRI), and Indian Institute of Horticultural Research (IIHR). This collaboration would be key to testing and validating appropriate technologies for commercially significant crops across different regions. In the long run, a sustained partnership between technology and agricultural institutions is essential for the continual development and application of smart agriculture. This integrated approach will ensure the sustainability and scalability of smart agriculture, ultimately supporting the nation’s food security and economic growth. By merging the strengths of both technology and agriculture, we can craft a resilient and efficient agricultural sector capable of meeting the demands of a growing global population.

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