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Precision Farming : "A Way Forward in Vegetable Science"

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ABSTRACT

The demand for vegetable crops is steadily increasing and meeting it necessitates the integration of technology for optimal resource utilization, resulting in better output per product of inputs and superior product quality. Precision agriculture is one of the most cutting-edge technologies for sustainable agriculture that has exploded in popularity in twenty first century. Precision farming entails the application of products and methods to control temporal and spatial variability in all aspects of gardening generation in order to improve crop performance and setting quality (Lee *et al.* 2010). This innovative technology necessitates efficient resource management via site-specific hi-tech interventions. A comprehensive precision agriculture strategy encompasses crop planning, tillage, planting, chemical treatments, harvesting and post-harvest processing. Precision vegetable farming is a modern approach of increasing crop output by utilizing cutting edge technologies such as cloud computing, Internet of Things (IOT), Artificial intelligence (AI) and achine Learning (ML). The fundamental goal of precision agriculture is to boost output by optimiz-ing supplies such as water, pesticide sprays, plant nutrition, for which, prescription maps are critical, since they allow farm owners to quantify information needed for usable plants at any stage of growth. Protected cultivation is one of the most important applications of precision farming, which has been rapidly growing with the goal of balancing maximum yields with resource efficiency optimization through close monitoring of environmental variables and improved culture techniques. Different forms of protective cultivation procedures include greenhouses/polyhouses, low tunnels and mulches. Protected agriculture makes considerable use of soilless cultivation to gain better control over the growing environment and eliminate soil water and nutrient status problems. The most prevalent soilless culture methods are hydroponics, aeroponics and aquaponics. These advanced technologies and techniques used in soilless vegetable growing are referred to as "next generation crop science" and they have the potential to pave the way for the establishment of a new civilization in space. The lack of highly sophosticated technical centers for PA, specific software for PA and the poor economic status of general Indian farmers should all be taken into account in the country's future precision agriculture adoption strategy. Precision farming adoption can be aided by influencing farmers' attitudes toward modern technology through research, development and subsequent popularization of low-cost electronic gadgets that can increase small farmers' earnings.

Keywords Precision farming, Protected cultivation, Soilless culture, Vegetables.

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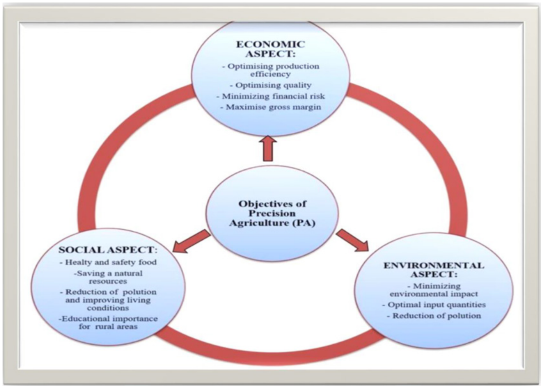

Fig. 1. Representation of precision agriculture goals (Figure source: Whelar and Taylor 2013).

INTRODUCTION

Precision agriculture is a modern crop production concept which blends cutting-edge information technology with a long-standing agricultural operation. Precision farming can be defined as an integrated information and production-based farming system that is designed to increase long term, site-specific and whole farm production efficiency, productivity and profitability while minimizing unintended impacts on wildlife and the environment (US House of Representatives 1997). Precision agriculture's performance is dependent on a precise assessment of variability, its control and evaluation in the space-timeband in crop production (Dwivedi *et al.* 2017). (Fig. 1).

The concepts of precision agriculture were originally articulated in Bulletin 346 of the University of Illinois, Experimental Agricultural Station in 1929, by the creative initiative of CM Linsley and FC Bauer as cited by Goering (1993). In the late 1980s, the current notion of precision agriculture in cropping systems gained hold with the completion of grid-based sampling of soil chemical properties with newly built variable-rate application (VRA) equipment for fertilizers. Pierre Robert is known as the "Father of Precision Agriculture" because of his strong support for precision farming philosophy and organization.

Precision farming, precision horticulture, site-specific farming (SSF), site-specific management (SSM), site-specific crop management (SSCM), variable rate application (VRA) and other terms are used to describe precision agriculture (Nabi *et al.* 2017). PA technologies have the potential to benefit a wide range of vegetable production systems through reducing costs associ-ated with labor, being more precise with the application of inputs and having a greater knowledge of the in-field variation in different parts of the farm.

Objectives of precision farming

Precision farming's goals can be summed up as follows:

Elements of precision farming:

a) Information
b) Technology
c) Decision support (management)

a) Information

Information is needed about crop characteristics, soil properties (topography, fertility status, texture, moisture content/retention, tillage needs, salinity, waterlogging), occurrence of pests (insects, diseases, weeds and others), weather/climatic conditions, other biotic and abiotic stresses, plant growth response, harvest and postharvest handling, marketing and market intelligence, socio-economic status of farmers.

b) Technology

PA is a multi-technological integrated agricultural management system. Among the most common technology aids are:

Global positioning system (GPS): One of the most cuttingedge technologies of the digital age is the Global Positioning System (GPS). The Global Positioning System (GPS) is a navi-gation system based on a network of satellites that allows users to record positional data (latitude, longitude and elevation) with 0.01 m accuracy (Lang 1992). Satellites send out signals that allow GPS receivers to calculate their location. The technology enables farmers to accurately identify field locations so that inputs (seeds, fertilizers, pesticides, herbicides and irri-gation water) can be applied to a specific field based on past input applications and perfor-mance criteria (Batte 2000).

Geographic information system (GIS): A geographic information system is a system for collecting, storing, manipulating, managing, analyzing and presenting spatial or geographic data. Geographic information system is a set of technology, software and methods for compiling, storing, retrieving and analyzing geographic features and location data in order to create maps. Numerous layers of data (e.g., yield, soil survey maps, rainfall, crops, soil nutrient levels and pests) are examined first and then used to understand the correlations between the various components influencing a crop on a specific site using computerized GIS maps (Ahmad and Mahdi 2018).

Variable rate technology (VRT): Variable-rate technology (VRT) is a piece of equipment that can adjust the application rate and mixture as it goes over the field. Pesticide, herbicide and seeding application rates are adjusted by VRT to complement soil potentials or problem areas (Adamchuck and Mulliken 2005). A variable rate system can also keep track of actual application rates as well as GPS coordinates (Sökefeld 2010).

Yield monitors: Crop yield monitors are devices that measure crop production and are mounted to harvesting machinery. The yield data from the monitor, as well as positional data from the GPS device, are captured and saved at regular intervals. The yield data is obtained using GIS software, which then generates yield maps (Nabi *et al*. 2017).

Remote sensing: Remote sensing is the science and practice of gathering data about the earth's surface without physically touching it. This is accomplished by capturing energy radiated or reflected from the earth's surface. The data is then processed and evaluated and the results are used to create a prescription map for variable rate applications.

c) Decision support (management)

A precision farming decision support system is designed to provide direction to farmers, agricultural professionals, researchers and other intellectuals in making various farmingrelated decisions, as well as access, display and analyze data with spatial content and meaning. An agricultural decision support system (ADSS) is a human computer system that uses data from a variety of sources to provide farmers with a list of recommendations to assist them in making decisions in a variety of situations (Zhai *et al.* 2020). The suggested precision farming decision support system is designed to offer correct information or data and to help farmers make the best judgments possible. The PHP programing language is used to create the decision support system (Singh and Sharma 2013).

Processes involved in adoption of precision farming in vegetables

Laser land levelling

Land levelling is used to improve the soil surface and slope, distribute irrigation water more efficiently and prepare fields for various agricultural techniques (Brye *et al.* 2006). Laser levelling is a procedure that involves employing laser-equipped drag buckets to flatten the land surface (by 2 cm) from its mean elevation. This method employs huge horsepower tractors and soil movers equipped with GPS and/or laser-guided instrumentation to move the soil by cutting or filling to achieve the appropriate slope. A laser transmitter, a laser receiver, an electrical control panel and a twin solenoid hydraulic control valve make up the laser-controlled system. The laser transmiter sends out a laser beam, which is intercepted by the levelling bucket's laser receiver. The signal from the receiver is read by the control panel on the tractor, which then releases or locks the hydraulic control valve, allowing the drag bucket to be lifted or lowered.

Benefits of laser land leveling

1. There is a consistent level of vegetation cover (Meral and Temizel 2006).
2. A 10%–25% boost in crop output.
3. Water loss was reduced by 25% during the application of water.
4. A 35–45% reduction in irrigation water consumption (Singh *et al.* 2008, Chhatwal 1999).
5. This method reduces weed problems while in-

Table 1. Use of different yield monitors for yield mapping of vegetable crops.

Crop	Method of yield mapping	References
Potatoes	Load cells under the conveying chains. 2-D vision system above the conveying belt.	Hofstee and Molema 2002, Rawlins *et al*. 1995.
Broccoli	Load cells and GPS to weigh the volume and position of the platforms transferring the crop in the field on the go	Rains *et al.* 2002 Saldana *et al.* 2006.
Onions / Watermelons	Dividing the field into block and weighing the platforms carrying the fruits per block.	Akdemir *et al.* 2005 Fountas *et al.* 2015 Sandri *et al.* 2014
Cabbage	Dynamic fluorescence index using measurements from a four-channel fluorescence multi-spectral imaging system to estimate water stress	Hsiao *et al.* 2010.

creasing cultivable land by 3–6% (Jat *et al.* 2004).

Mapping in plant attributes

Precision agricultural mapping comprises acquiring geospatial data on plant or soil features and requirements in a timely manner, then implementing and prescribing site-specific treatments to maximize yield while also safeguarding the environment. Precision maps are a critical tool in precision agriculture that serve as a road map to success. Satellite, autonomous platform, unmanned aerial system and stationary sensor at the tree are all viable sensor platforms (Zude-Sasse *et al.* 2016).

Soil mapping in vegetables

Soil mapping comprises locating and identifying the many soils that exist, collecting information about their location, natural qualities and potential uses and displaying this data on maps and in accompanying documentation to show the geographic distribution of each soil. The term "digital soil mapping" refers to the use of geospatial technology for mapping soils in a broad sense (DSM). The building of geographically referenced soil databases based on quantitative correlations between spatially explicit environmental data and measurements obtained in the field and laboratory is known as digital soil mapping (McBratney *et al*. 2003). DSM approaches are used to examine the geographic distribution of soil classes (e.g., soil series) and/or soil attributes (e.g., soil organic matter) at various sizes (from individual fields to countries) and have proven useful in producing more quantitative, accurate and exact soil maps. In plants, EM38 sensors, Veris and other soil mapping technologies are used.

Yield mapping

Yield mapping is a methodology for gathering georeferenced data on crop yield and attributes, such as moisture content, as the crop is harvested. Yield maps are created using a DGPS receiver and a series of instantaneous yield data points from the yield sensor compotes. The yield and position data are sent to a computer, which employs interpolation techniques to create a field yield map. The yield map tells the farmer which portions of the field are producing better and which are not (Ahmad and Mahdi 2018). Table 1 summarises yield monitors for a variety of vegetable crops.

Precision seeding

Precision seeding is the process of putting a specific number of seeds at a specific depth and spacing.

Precision seeding has the following benefits:

1. Seed expenditures are reduced because only the seed that is required is planted.
2. Because seeds are evenly spread, crop consistency is improved. This often results in more consistent and high-quality product, fewer harvests and higher yield.
3. Increased yields of 20 to 50% since each plant has ample room to grow and develop.

Table 2. Protected cultivation in vegetable crops (Singh and Sirohi 2006).

Crop	Type of protected structure	Duration	Average fruit yield (t/ha)
Tomato	Semi climate controlled greenhouses	10-11 months	200-210 t/ha
Cherry tomato	Semi climate controlled greenhouses	10-11 months	80-90 t/ha
Sweet pepper	Semi climate controlled greenhouses	9-10 months	40-50 t/ha
Parthenogenic cucumber	Naturally ventilated greenhouse	-	100-110 t/ha
Summer squash	Plastic low tunnels	-	70 t/ha

4. Seeds are placed at shorter distances, resulting in a more consistent planting depth and less dispersal.
5. Thinning has been reduced or eliminated.

Types of precision seeders in vegetable crops

Belt type seeder: In this form of seeder, circular holes are punched in a belt to suit the seed size and the holes are spaced at specific intervals along the belt. This planter is suitable for tomato and watermelon seeds.

Plate type seeder: Seeds are dropped into a notch in the plate and then delivered to the drop location with this sort of seeder. This planter holds lettuce and snap bean seeds.

Vacuum type seeder: Seed is drawn against perforations in a vertical plate and agitated to eliminate extra seed in this sort of precision seeder. It works well with watermelon, cucumber and snap bean seeds.

Pneumatic type seeder: Seed is held against a drum in a pneumatic seeder until the air pressure is broken, at which point it falls into tubes and is blown into the soil. This planter is for large vegetable seeds such as sweet corn or snap beans.

Grooved cylinder type: This seeder requires round seed or seed that has been coated to make it round. Seven seeds fall from a supply tube into a slit in the top of a metal box, which is then deposited into a metal cylinder. The seeds fall out of a diagonal slot as the cylinder turns gently toward the bottom of the casing. Seeds no bigger than a pepper can be planted in this planter. This planter is for small seeds (lettuce to pepper).

Applications of precision farming

Protected cultivation

Protected cultivation is a cropping technique in which the micro-environment surrounding the plant body is controlled partially or completely according to plant needs during their growth period in order to maximize production and save resources (Nair and Barche 2014). Protected vegetable agriculture provides growers with distinct advantages in terms of quality, productivity and market price. Greenhouse/ polyhouse farming, pest resistant net house, shade net house, plastic tunnel and mulching, raised beds and drip irrigation are some of the protective cultivation strategies that are used depending on the climate.

The protected cultivation of vegetable crops may be a valuable technology for farming community because it's a cost-effective technique. The selection of the vegetable crop or variety to be grown in a greenhouse or in protected structures is usually made on the idea of the situation, season and therefore, the

Table 3. Vegetable cultivation in various types of passive solar greenhouses (Angmo *et al.* 2019).

Type of green-house	Crop	Variety	Season	Yield / poly-house
Polytrench green-house	Spinach	Delta	Winter (Mid October to early March)	22.5±4.2 kg
Polytrench green-house	Capsicum	California wonder	Summer (Mid May to early October)	42.3±6.6 kg
Polyench green-house	Brinjal	Janak	Summer (Mid May to early October)	60.6±8.55 kg
Polyench green-house	Spinach	Delta	Winter (Mid October to early March)	232±47.6 kg

physical size of the structure and also on the idea of the economics of vegetable production. Tomato, capsicum and cucumber are widely grown vegetables under green houses and provides higher returns (Chandra *et al.* 2000). Different types of protected structures have been used to grow variety of vegetable crops under varying climatic conditions (Tables 2, 3).

Soil less culture

Soilless culture is man-made process of providing plants with support and a reservoir for nutrients and water. Often called solution culture or water culture, the tactic was originally termed as hydro-ponics (i.e., "water working") by W. F. Gericke in the 1930s.

Solution culture

Based on water flow

Static solution culture: Plants are raised in nutrient solution-filled containers such as glass jars, plastic buckets, tubs or tanks in static solution culture. For each plant, a hole is drilled in the reservoir's lid. Aerated solutions are common, however they can also be unaerated.

Continuous solution culture: The nutritional solution flows continuously past the roots in continuous solution culture. As a result, the roots aren't buried in water. Instead of individual jars or buckets for the plants, large storage tanks are frequently used in this type of setup.

Based on movement of nutrient solution

Active system: Electric pumps deliver solutions to the plant roots in active systems, while a gravity system drains excess solution that can be recycled and reused. NFT system, deep water culture system, drip system and dutch bucket method are the sev-eral types of this system (Table 4).

Passive system: Plant roots stay in contact with the nutrient solution in this technique and the plants are maintained by the suspension method. The primary downside of this system is that it is difficult to main-

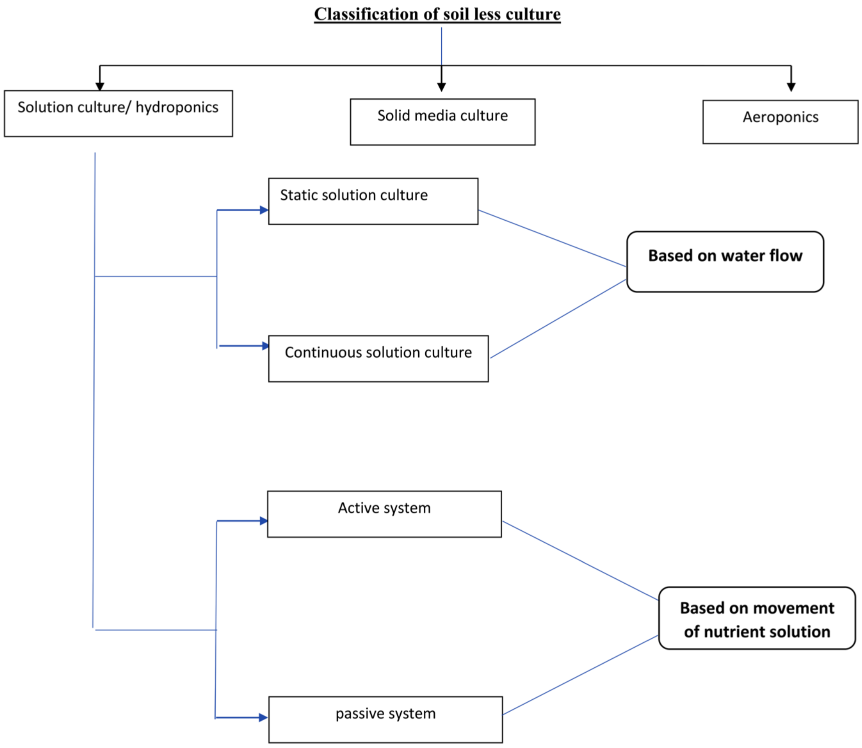

Table 4. Illustration of different types of active hydroponic systems.

Active system types	Description
NFT system	The N.F.T uses a continuing flow of the growth Technology nutrient solu-tion (therefore no timer is required). The solution is siphoned off from a reservoir into the growing tray. The growing tray requires no growing me-dium. The roots derive nutrients from the flowing solution. The downward flow pours back to the reservoir to be recycled again. Pump and electric maintenance is important to avoid system failures, where roots can dry out rapidly when the flow stops Solanki *et al.* 2017
Deep water culture system	Roots of plants are suspended in nutrient rich water and air is provided di-rectly to the roots by an air stone. Hydroponics buckets system is classical example of this system. Plants are placed in net pots and roots are suspended in nutrient solution where they grow quickly in a large mass. This system works well for larger plants that produce fruits especially cucumber and tomato. Macwan *et al.* 2020.
Ebb and flow system	This is first commercial hydroponic system which works on the principle of flood and drain. Nutrient solution and water from reservoir flooded through a water pump to grow bed until it reaches a certain level and stay there for certain period of time so that it provides nutrients and moisture to plants. Sharma *et al.* 2018.
Drip system	The drip hydroponic system is extensively used method among both home and commercial growers. Water or nutrient solution from the reservoir is delivered to individual plant roots in appropriate proportion with the assistance of pump. Rouphael and Colla 2005.
Dutch bucket method	Dutch bucket method was used in Netherlands for the first time to grow cu-cumbers, tomatoes and roses. In this system, a bucket (2.5 gallon) is used to grow plants. A pump is used to recycle the excess nutrient solution. George and George 2016.

tain plants as they grow. It is, however, incredibly simple to install. A passive hydroponics system is the wick sys-tem.

Wick system: This is the most basic hydroponic system, requiring no electricity, a pump, or aerators (Shrestha and Dunn 2013). Plants are placed on soilless media such as vermiculite, perlite, or coconut coir, with nutrient solution supplied by lamp wick or nylon or polyester wick. This strategy is best for little plants. It works for spices and herbaceous plants, but not for plants that need a lot of water.

Solid media culture

Plants are planted in various substrates such as rock-wool, hydroton, coir, perlite and pumice using this approach (Table 5). Vegetable crops were grown using a va-riety of hydroponic systems, including gravel film technology, recirculating hydro-ponic systems and so on (Table 6).

Table 5. Classification of media employed in solid media culture of hydroponics.

Organic media	Inorganic media Natural media	Synthetic media
Sawdust	Vermiculite	Hydroton
Cocopeat	Rockwool	Foam mates
Peat	Perlite	Oasis (plastic foam)
Woodchips	Gravel	
Bark	Sand	
Sphagnum moss	Glasswool	

Aeroponics

The word “aeroponic” comes from the Latin words “aero” (air) and “ponic” (work). Aeroponics refers to plant growth that takes place in an air environment

Table 6. Vegetable growing under hydroponics.

Crop	Hydroponic technique involved	References
Swiss chard	Gravel film technique	Maboko and Plooy 2013
Lettuce	Recirculating hydroponic system	Maboko and Plooy 2009
Tomato	Nutrient film technique	Zekki *et al* 1996
Cabbage,Red Lettuce, Dill and Mallow	Nutrient film technique with rice husk biochar alone and in combination with perlite as substrates	Awad *et al*. 2017
Spinach	Floating System	Mwazi *et al*. 2010.
Tomatoes and Pepper	Drip system	George and George 2016.

Table 7. Production of vegetable crops using aeroponic technique.

Name of crop	References
Lettuce, Spinach	Khan *et al*. 2018.
Potato	Tunio *et al*. 2020
Tomato	Biddinger *et al.* 1998
Chicory	Abou-Hadid *et al*. 1994
Cucumber	Park and Chiang 1997
Yam	Maroya *et al*. 2014.

(Lak-kireddy et al. 2012). Aeroponics is the development of plants without the use of soil or water as a medium while maintaining all of the critical plant growth parameters (temperature, pH, humidity, electrical conductivity of nutrient solution) (Kaur and Kumar 2014). The idea behind this technique is to grow plants with their roots in a nutrient mist (Zobel *et al.* 1976). The soil-less aeroponic technology has been used to grow a range of foods, including tomato, spinach and chicory (Table 7).

Aquaponics

Aquaponics is a high-yield, low-water, low-fertilizer agricultural production method that combines hydroponic and aquaculture systems to produce many cash crops with minimal water and fertilizer use. When these two systems are combined, an all-natural nutrient solution for plant development is created, while a waste product that is normally discarded as wastewater is avoided (Surnar *et al.* 2015). Aquaponics is a concept that involves growing plants in a hydroponic system utilizing nutrient-rich water from a fish-raising tank (Mamat *et al*. 2016). Aquaponics has been used to cultivate a variety of vegetable crops (Table 8).

Table 8. Aquaponics technique of growing vegetable crops.

Crop	Scientific name	References
Spinach	*Spinacia oleracea*	Petrea *et al*. 2014
Tomato	*Solanum lycopersicum*	Surnar *et al.* 2015
Spinach	*Spinacia oleracea*	
Red amaranth	*Amaranthus tricolor*	
Green-red amaranth	*Amaranthus cruentus*	Mamat *et al.* 2016
Water spinach	*Ipomoea aquatica*	
Chives	*Allium schoenoprasum*	Savidov *et al.* 2007, Love *et al*. 2015.
Parsley	*Petroselinum crispum*	Savidov *et al.* 2007.

Table 9. Vertical farming in vegetables.

Crop	Source
Tomato	Balashova *et al***.** 2019
Lettuces, Kales, Chard and Collard Greens, Chives and Mint, Basil (Sweet, Lemon, Cinnamon), Oregano, Parsley, Tomatoes, Strawberries, Thyme, Radish, Ice Berg, Spinach	Royston and Pavithra 2018
Chinese Cabbage, Lettuce, Water Spinach, Red Chilli	Utami *et al.* 2012.
Carrot, Radish, Bean, Beet, Cherry Tomato and Various Herbs.	Reja *et al.* 2019
Lettuce, Basil, Spinach, Kale, Arugula, Peppers, Tomatoes, Stevia, Strawberries and Brussel Sprouts.	Al- Kodmany 2018.

Vertical farming / sky farming

Vertical farming (VF) is an agricultural technology that allows for large-scale food produc-tion in high-rise buildings by altering ambient conditions and nutrient solutions to hydro-ponic crops utilizing cutting-edge greenhouse methods and technologies. (Abel 2010, Banerjee and Adenaeuer 2014, Despommier 2010, 2011). Vertical farming's main purpose is to produce more food per square meter, hence crops are grown vertically to achieve this. To maintain the precise light level in the space, a perfect mixture of natural and artificial lighting is used. Lighting efficiency is improved by the use of technologies such as rotating beds. To compensate for this, the vertical farming system makes use of a number of sustainable ele-ments. Vertical farming, in reality, consumes 95% less water than ordinary agriculture (Royston and Pavithra 2018). Vertical farming, sometimes known as sky farming, has been used to grow a variety of food crops such as tomato, beet and Swiss chard (Table 9).

Table 10. Classification of mulches.

Organic mulches	Inorganic mulches
Leaves	Black mulch
Grass clippings	Transparent mulch
Peat moss	Double colored mulch
Wood chips	Degradable mulch (photo degradable mulch and biodegradable mulch).
Bark chips	
Straw mulch / field hay	
Pine straw	

Table 11. Use of different types of mulches in vegetable growing.

Crop	Type of mulch used	References
Tomato	Colored plastic mulch (Sil-ver-black, white-black, Yel-low-black, red-black, blue-black and pervious black	More *et al.* 2019
Watermelon and Potato	Straw mulch	Johnson *et al.* 2004
Summer squash	Organic and plastic mulches	Bhat *et al.* 2011
Okra and squash	Polyethylene black plastic mulch	Mahadeen 2014
Potato	Plastic film mulching	Wang *et al.* 2019

Mulches and plastic films

Mulch is any organic or inorganic covering material that is put to the soil surface to prevent evaporation losses. This material can be grown and maintained in place or it can be grown and modified before being placed, or it can be processed or made before being placed. Mulch is used for a variety of reasons, including soil moisture conservation, improving soil fertility and health, limiting weed growth and improving the aesthetic appeal of the area. Mulch, whether alive or dead, blocks the light that weed shoots require to emerge and flourish and some types of mulch also have allelopathic properties (Liebl *et al.* 1992, Zimdahl 1999).

Plastic and non-plastic components such as plastic mulch, plastic film, row cover, drip irrigation, fertigation and windbreaks are important inputs to a plasticulture system. Mulches are divided into two categories: Organic and inorganic mulches (Table 10). Mulches of various kinds were used as covering materials in vegetable crops, including straw mulch and polyethylene black plastic mulch (Table 11).

Recent developments in vegetable precision farming

Artificial intelligence

Artificial intelligence (AI) is a highly creative tool that utilizes technology to replicate human intellect and ability activities, notably computer systems, robotics and digital equipments. The primary purpose of artificial intelligence in agriculture is to give accuracy and anticipating decisions in order to maximize productivity while conserving resources (Patel *et al.* 2021). Artificial intelligence tools are aiding farm-ers in designing more efficient weed-control successful strategies. Eventually, the use of advanced AI-based technologies has benefits on the agri-food supply chain, such as significantly lowering employee training costs, shortening the time needed to fix dilemmas, limiting the amount of miscalculations, reducing the amount of user intercession and offering algorithmic good, exact and reliable decision-making at the right time at a minimal cost (Kamilaris and Prenafeta-Bold 2018). There are nu-merous examples of AI-applied technology in the agri-food sector, including those of robotics and mechatronics (Krishna 2016), drones (Krishna 2016, 2017), geographic information systems (GISs), blockchain (BC) (Zhao *et al.* 2019) and sat-ellite navigation (Krishna 2016). Innovative machines widely known as “agribots” are currently utilized in agriculture for a multitude of activities including soil prepa-ration, seed sowing, weed and insect control, irrigation, fertilization and finally, grain and fruit harvesting while limiting effort and energy cost (Krishna 2016, Kootstra *et al.* 2021, Sennaar 2021, Bac *et al.* 2014, Zujevs *et al.* 2010-2015). Agri-cultural drones can now deliver water, fertilizer, herbicides and insecticides along with film, capture photographs and generate maps of plants and fields in real time to enable farmers in making management decisions (Krishna 2016, Huuskonen and Oksanen 2018). Another technology that addresses customer concerns regarding food origin, quality and most importantly, safety is block chain. Block chain pro-vides transparency, trust, certification and traceability of food product supply chain from farm to the table, where every single process and data are timely registered, saved, anonymized and secured, not in a single web system nor under a single control, but in an unified and comprehensive platform database where every person can access and participate in

Table 12. Sensor technologies in vegetable precision farming (Tripodi *et al*. 2018).

Vegetable	Character	Instrument with sensors
Solanum lycopersicum	Ripeness	Im Spector V9
Leafy vegetables	Chlorophyll content	ASD Fieldspec FR spectroradi-ometer
Citrullus lanatus	Lycopene, -Carotene and Total soluble solids	NIR On-Line® X-One
Solanum lycopersicum	Harvest time	AgroSpec VIS–NIR spectrophotometer
Phaseolus vulgaris	Photosynthetic traits, morphological parameters and shoot architecture	Growscreen Fluoro
Brassica rapa sub-species pekinensis and *Chinensis*	Quality	Fluor Pen FP 100 fluorimeter
Solanum melongena	Fruit morphology and shape	Scanner imaging

transactions.

Internet of things (IOT)

The internet of things (IoT) is a broad concept that represents the linking of multiple everyday objects through the use of the internet. Every object in the internet of things idea is interconnected to one another by an unique identifier, potentially allowing it to automatically transfer information through the network without requiring human communication (Morais *et al.* 2005). The aim of IoT is to connect every person and every object through the internet (Shahzadi *et al.* 2016). The internet of things (IoT) enables farmers to digitize the activities of monitoring crops and livestock farming, in some instances effectively allowing network access to their farms (Talavera *et al*. 2017), highly developed platforms use sensors that take values that must be managed and investigated with high precision to make it possible for successful decision-making that generates benefits (Khanna and Kaur 2019), mostly comprising of wireless sensor networks and actuators (Lopez *et al.* 2017) , take complete control of autonomous irrigation systems (Castro – Silva 2016), a monitor-ing system of environmental parameters powered by solar energy, a program based on Digi Mesh and Wi-Fi that can be used in both rural and urban contexts, and a transmission system with IoT platforms (Cuenca *et al.* 2017, Cevallos *et al*. 2018) and computer networks focused on precision agriculture technologies (Orozco and Ramirez 2016). IoT systems can assure the quality of plant-based goods for human consumption by using sensors and actuators, allowing the manufacturer to offer new services and have command over information gathering, monitoring and decision-making processes. IoT systems can assure the quality of plant-based goods for hu-man consumption by using sensors and actuators, allowing the manufacturer to offer new services and have command over information gathering, monitoring and decisionmaking processes. Different types of sensor technologies are utilized in precision vegetable farming (Table 12).

CONCLUSION

Despite its enormous success in rich countries, precision farming is regarded as a pipe dream in underdeveloped countries. Precision farming provides several potentials for farmers in various nations, including India, to identify improved high producing location specific crops and in reality, a farmer can become a breeder by using the PA system to produce better and higher producing varieties.

The most significant impediment to the adoption of novel vegetable farming practises is fragmented landholdings, with over 80% of farmers being marginal and small farmers unable to make large upfront investments in precision farming. The variability of cropping systems and market imperfections, land ownership, infrastructure and institutional constraints, a lack of local technical skills and knowledge and technical gaps among farmers are all key obstacles restricting the implementation of smart farming in vegetables. The most crucial step in moving PA forward will be to have a large pool of engineers, scientists, and agriculturists who can work on various aspects of the technology. Furthermore, in order to build smart technologies in PA, government organisations such as ICAR, industries and farmers must communicate, engage and work together. While technically viable, more research is needed to clarify the economic and environmental benefits of precision agriculture's numerous components. Finally, the success of precision agriculture is mainly determined by how well and, as a result, how rapidly the information required to guide new technologies is discovered.

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