Chapter 29
Modern Concepts and Techniques for Better Cotton Production

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Abstract Sustainable cotton production in current environmental conditions is under threat due to climatic variability and shortage of ever-decreasing resources for agricultural crops. There is dire need to improve the cotton production to fulfill increasing demands of the ever increasing world population which will rise up to nine billion till 2050. Poor soil health, poor water quality and water shortage, insect pest complex, and unpredictable climatic patterns are predominant problems to cotton production. Hence, there is a great challenge to manage cotton crop in a sustainable fashion without the degradation of soil, water, and environment due to climate variability. There are several factors associated with low production of cotton including improper sowing and picking, poor pesticide spraying approaches, inappropriate amount and time of irrigation, processing and ginning through inappropriate and primitive procedures, heat stress, lack of disease- and pest-tolerant varieties, improper nutrient management, improper disease management, and improper weed management. It is the need of the hour to adopt the modern technologies and applications for sustainable cotton production. There are several modern technologies which can increase the production of cotton and make the idea of sustainability feasible because of their site-specific management of

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all agricultural inputs. GPS, GIS, and remote sensing technologies make the precise seeding of cotton seed, fertilizers, and pesticides. IPM, IWM, and INM are the well-developed modern concepts which not only reduce the cost of production but also mitigate the emission of greenhouse gases. For sustainable cotton production, implementation of these modern concepts is crucial so that the human beings will get benefits in the future. Therefore, this chapter will be focused on the recently developed technologies which can be sustainably utilized for the better management of cotton crop across the world. This chapter will explore the importance of Decision Support system (DSS) for sustainable cotton production; role of GPS, GIS, and remote sensing for identifying site-specific factors such as soil quality indicators; importance of transgenic cotton; impact of mechanical sowing and picking on sustainable cotton production; use of UAVs for nutrient and pesticide management; and impacts of modern concepts on increasing agronomic production and advancing global fiber and oil security.

Keywords Sustainable cotton production · GIS · GPS · Remote sensing · Fiber security

Abbreviations

ARIMA	Autoregressive integrated moving average
ARMA	Autoregressive moving average
CSM	Cropping system model
DSS	Decision support system
EC	Electrical conductivity
ET	Evapotranspiration
FDR	Frequency domain reflectometry
GIS	Geographic information system
GPS	Global positioning system
GSM	Global system for mobile communication
IPM	Integrated pest management
IRS	Information retrieval system
IWM	Integrated weed management
LAI	Leaf area index
MARS	Marker-assisted recurrent selection
MAS	Marker-assisted selection
NDVI	Normalized difference vegetation index
NMR	Nuclear magnetic resonance
PA	Precision agriculture
RS	Remote sensing
SCY	Seed cotton yield
SEBAL	Surface energy balance algorithm for land
UAV	Unmanned aerial vehicle
VRA	Variable rate application
VWC	Volumetric water content
WHO	World Health Organization
WUE	Water use efficiency

29.1 Introduction

29.1.1 Significance of Modern/Advanced Technology for Sustainable Cotton Production

Modern technology plays an important role in agricultural productivity. Today with the implementation of modern technology, the farmer is able to grow crops in different soil conditions by minimum application of input resources. Inventions of modern machinery reduce farmer effort which are used for manual working in field and also reduce production time. By using this machinery, farmers can improve soil fertility, sowing method, fertilizer application, and crop protection during the whole season. In sustainable cotton production, some procedures such as integrated nutrient, weed, and pest management are involved. By using modern technology and integrated management together, it will increase the overall SCY with minimum inputs and the farmer gets maximum profit. These increases in production will boost the country's GDP. Including all of above it is also found that precision agriculture reduces the fossil fuel consumption which pollutes the environment.

29.1.2 Recent Advancements in Cotton Production

Modern technology implementation in cotton production improves its yield and reduces human efforts (Usman et al. 2009; Ahmad et al. 2014; Abbas and Ahmad 2018; Ahmad and Raza 2014; Ali et al. 2011, 2013a, b, 2014a, b). Application of information technology enables the farmer to think innovatively and make a decision at the right time (Ahmad et al. 2017, 2018; Amin et al. 2017, 2018; Khan et al. 2004; Rahman et al. 2017, 2018; Tariq et al. 2017, 2018). Other technologies including robots, satellite imagery, GPS, GIS, and RS are used in precision agriculture. These technologies provide information about crop health, nutrient status, irrigation management, and cotton yield (biological, SCY). There are also new resistant and high-yielding cotton varieties (transgenic cotton) (Rocha-munive et al. 2018) and variety selection methods such as MAS (Lema 2018) and MARS (Ribaut et al. 2010). Nano-biotechnology is also used in agriculture to protect plants against pathogens and monitor crop growth. It is also used to study the role and regulation of plant hormones. For fertilizer management, UAVs (Daughtry et al. 2018), sensors (Jia et al. 2014), and variable rate technology have recently been adopted for precise fertilizer application. Sprinkler and drip irrigation method increases the WUE in crops as well as in orchards.

29.1.3 Application of DSS for Sustainable Cotton Production

DSS is an interactive computer program that contains a wide range of information needed by decision makers to solve unstructured and difficult problems about uncertain and complex situations by accessing the data processes and analytical reasoning. These computer-based programs are being used for solving problems regarding multiple disciplines in agriculture to get specified objectives (Mir et al. 2015; Malik et al. 2018). For instance, farmers frequently need information to make decisions about which quantity of manure is needed to spread in cotton crop. For this purpose there are many tools for decision support such as mobile applications that quantify the nutrient amount present within manures applied in crop at varying amounts (Rose et al. 2018). Fertilizer management is adopted for managing and optimizing fertilizer use in crop production to enhance crop yield and decrease fertilizer input cost. Another technique, IrriSAT, which has been devised based on weather for irrigation scheduling, quantifies the amount of water required for cotton crop. This program was developed by the Commonwealth Scientific and Industrial Research Organisation (CSIRO) for the Cotton Research and Development Corporation (CRDC) (Vleeshouwer et al. 2015). Many studies reported that farmer engagement is noticeably very low with computer-based applications for decision support (Rahman et al. 2016; Kerselaers et al. 2015; Lindblom et al. 2017; Ogunti et al. 2018). To resolve this problem, various researches have evaluated how DSS tools can be updated and supplied to increase their use (Kerselaers et al. 2015).

29.2 Soil Sampling and Analysis Using Advanced Technologies for Better Cotton Production

Soil is the natural and valuable nonrenewable resource which contributes in sustainability of the ecosystem throughout the world, but soil productivity and fertility is under threat due to climate change across the world (Incrocci et al. 2019). According to the Soil Science Society of America (2013), soil plays a vital role in (1) formation of basic ecosystem, (2) provision of essential nutrients to crops and forests, (3) biomass production in forestry as well as in agriculture, (4) growth medium, (5) carbon pool formation, (6) filtering of our water, and (7) regulation of Earth's temperature. In an agricultural point of view, soil is a key factor for crop production since it depends on soil fertility and soil health. Soil fertility could be determined by soil testing to evaluate the fertilizer status to achieve maximum crop yield and minimize the potential losses to the environment (Dawson and Knowles 2018). There are advanced technologies (GIS and GPS) for soil testing to evaluate the soil topography, soil health, and soil management; soil mapping can be done by adopting the latest technologies available.

29.2.1 Use of GIS and GPS for Cotton Crop Production

The application of GIS in agriculture was started in the mid-1990s, with the invention and broader use of GPS for precision agriculture. GIS is able to manage large data of soil. The data of organic matter content and nutrient status of soil are very important for sustainable production (Senthurpandian et al. 2010). GIS produced soil fertility status spatially as well as temporarily for site-specific management of resources (nutrients, water) for sustainable crop production (Patil et al. 2011). For this purpose GIS technology can simplify as well as help in dealing with soil variability (Sarmah et al. 2018). The geographic information system enables the researcher to study the soil properties by spatial visualization in the procedure of vector and raster maps (Glowienka et al. 2016).

GPS is a form of satellite network revolving around the globe. This system operates by determining reflecting GPS signals from the Earth's surface. It requires satellites of GPS which provide radar transmitters and GPS receiver. The position of radar transmitters and GPS receiver should be co-located, but the angle of incidence may vary over the selected points of soil, but in general it is above 30° (Privette et al. 2011). Mapping and determining variations in soil properties of a field needs accurate information of position from where samples were taken. In GPS soil sampling, grid method of sampling is used, and location of sampling point should be accurate to develop soil data layer.

29.2.2 Application of Remote Sensing for Soil Sampling in Cotton Field

Remote sensing is a method of data collection that records the quantity of electromagnetic radiation emitted or reflected from substances on Earth at different wavelengths. These radiations travel from substance/source directly through space vacuum or are reflected indirectly and are captured by specific sensors (Jensen 2009). Different objects have different reflectance properties such as rock, soils, water, vegetation, etc. Hence, RS could help in characterization of soil attributes (Grunwald et al. 2015). Application of remote sensing in soil is based on soil spectral reflectance. The nature and shape of spectral reflectance curve of a soil depends on chemical and physical properties of soil (Wadodkar et al. 2014). Application of remote sensing in soil sampling is mainly in spatial valuation of soil fertility in the sense of nutrient deficiency by soil fertility map preparation. The remote sensing has been applied for soil classification based on soil crusting, salinization, texture, moisture, and mineralogy.

29.2.3 Advanced Techniques in Soil Analysis

29.2.3.1 X-ray Spectroscopy

X-ray spectroscopic techniques are widely used in soil science, environmental sciences, and agronomy. Techniques utilizing diffuse reflectance of near- and mid-infrared rays have been effectively used to evaluate the characteristics of a wide range of soils (Minasny et al. 2009; Kamau-Rewe et al. 2011; Towett et al. 2013), and they have also been used at wide scale coupled with enhanced geostatic procedure. It is a quick way for estimating composition of soil samples. For sample analysis it does not require acid digestion of the samples; thus it may be used as a screening tool.

29.2.3.2 Phosphorus-31 NMR Spectroscopy

Evaluating the dynamics and form of soil phosphorus is important to sustain agricultural productivity with minimum environmental risks. An emerging technique, phosphorus-31 NMR spectroscopy, was used by Newman and Tate for the first time in 1980 on extracts of soil to evaluate the soil phosphorus (P) and its forms in soil, preferably organic P; nevertheless, it must be operated accurately to give meaningful results (Cade-Menun and Liu 2014; Cade-Menun 2017). Total P of soil is expressed generally in mg/kg ranges; as concentration of soil extracts increases, the total P concentration increases as well in every NMR sample, significantly enhancing NMR response (Cade-Menun 2017). In this technique, for characterization of organic P, a mixture of ethylenediaminetetraacetic acid and sodium hydroxide is used with the soil extract (Doolette and Smernik 2015).

29.3 Modern Technologies for Cotton Genotype/Cultivar Development

29.3.1 Use of Modern Technology for Selection of Genotype/Cultivars for Different Ecological Zones Under Contrasting Climate

Plant population is a key factor in contributing to overall cotton yield. Selection of cultivar under contrasting environment is very important, and breeders also have developed environment-specific varieties. Some techniques are also used for selection of varieties such as marker-assisted selection, marker-assisted recurrent selection, seed health test, and germination potential.

29.3.1.1 Marker-Assisted Selection (MAS)

Introducing a new variety by traditional and conventional breeding method could approximately take 8–10 years to develop it. Breeders are interested in a new method to speed up this process. By the invention of marker-assisted selection, a large number of genetic material can be identified (Lema 2018). MAS is known as a breeding technique in which selection and detection of DNA marker are combined into a traditional and conventional breeding program (Jiang 2013). The efficiency and effectiveness of traditional and conventional breeding for selecting genotype can be improved by a large range of molecular markers (Kumar et al. 2011). Breeders would be able to bypass the traditional method of phenotype-based selection by wide use of molecular markers that are included in growing plants to physiological and harvesting maturity and also observe physical characteristics to assume fundamental makeup. MAS can be used at seedling stage for selection which provides high efficiency and precision at a low cost (Farokhzadeh and Alifakheri 2014).

29.3.1.2 Marker-Assisted Recurrent Selection (MARS)

Genotype selection under different ecological zones is also possible by MARS, and it is a technique in which molecular markers are used to identify and select various genomic regions that are involved in complex trait expressions to collect the best genotype within populations (Ribaut et al. 2010). The efficiency of complex traits by MARS is possible, but a disadvantage is that the selection cycle is long which restricts the practical use of this new breeding method (Lema 2018) because it takes 5–6 years for genotype selection. Molecular markers working under genotypic assays may be cheaper, faster, and accurate as compared to conventional phenotypic assays while depending on traits and conditions; thus these techniques may result in high efficiency in time, effort, and resource saving (Jiang 2013).

29.3.2 Transgenic Cotton

Biotechnology is used for genetic modification (GM) in which the genetic material of various living organisms is manipulated, modifying them to perform specific functions. In 1996, transgenic cotton was for the first time sown (James 2016; Rocha-munive et al. 2018), because non-*Bt* cotton failed due to pest pressure in cotton-producing areas (Terán-Vargas et al. 2005). Since the last two decades, transgenic cotton adoption has been increased globally resulting to a rise of about 42% in area in 2017–2018. The major problem of non-transgenic cotton was bollworms causing severe loss in SCY (Singh 2018). By using transgenic cotton, yield has been increased manifold around the world (Asghar et al. 2016) through controlling bollworms. Transgenic cotton, in the start of it, became popular through reduction in insecticide sprays against bollworm pests (Singh 2018). It is reported that *Bt* cotton is resistant to lepidopteran pests due to the presence of *cry* genes extracted from *Bacillus thuringiensis* (Bt). It showed resistance to larval stage of lepidopteran pests including *Helicoverpa zea*, *Pectinophora gossypiella*, *Spodoptera exigua*, and *Heliothis virescens* (Benedict et al. 1993; James 2016; Rocha-Munive et al. 2018).

29.3.3 Modern Concepts in Seed Testing and Viability

Seed is a very small and fragile embryonic plant and it is also the foundation of agriculture. Seed viability and quality are important factors in modern agriculture for optimum population and maximum yield (Tsedaley 2015). Seed viability is measured in which it is tested how seeds grow and develop into plants. Seed quality is an important characteristic for crop productivity as well as for food security under changing climate (Finch-Savage and Bassel 2016). Caverzan et al. (2018) reported that there are various factors which limit the growth and productivity of crops. Thus, the physiological quality of seed is more important for uniform establishment of crops. Seed vigor reflects several properties which determine the seed viability and quality and emergence potential of crops under variable climatic conditions (Finch-Savage and Bassel 2016).

29.4 New Concepts of Cotton Planting

29.4.1 New Concepts in Tillage for Seed Bed Preparation to Ensure Low GHG Emission

Soil tillage has a pronounced effect on soil tilth and balance between soil and greenhouse gases (GHGs) (nitrous oxide, carbon dioxide, and methane). The excessive emission of these GHGs leads to climate change and global warming (Mangalassery et al. 2014; Campbell et al. 2014). Krištof et al. (2014) reported that when tillage intensity increases, it results in high amounts of carbon dioxide emission from the soil into the atmosphere. Abdalla et al. (2016) concluded that emission of carbon dioxide is 27% more in tillage soils than in no-tillage soils in arid climate regions, while in humid climate regions, emission of carbon dioxide is 16% more in tillage soils than in no-tillage soils. To reduce the greenhouse gas emission from the soil into the atmosphere, conservation tillage (reduced, minimum, zero tillage, direct seeding) has been reported to be adopted as it decreases fossil fuel usage for field preparation and also enhances carbon sequestration in soil. Maraseni and Cockfield (2011) found that we can improve yield and reduce cost of production and greenhouse gas emission from soil through conservation tillage.

29.4.2 Mechanical Sowing of Cotton

The main objective of mechanical sowing is the uniform distribution of seeds at the optimum spaces and depth. The effects of optimal sowing are maximum germination, sprouting, and no competition for space, water, nutrients, and light resulting in improved yield (Turan et al. 2015). Mechanical sowing of cotton is possible by automated seed-cum-fertilizer drill, tractor-drawn planter. Mechanical sowing reduces the pressure of labor cost and time consumption. In automated seed-cum-fertilizer drill, seed and fertilizer are fitted together and placed simultaneously at specific line spacing. It is used in arid regions for cotton sowing. The advantages of this drill are that (1) fertilizer and seed are in separate compartments, (2) it opens the furrows at calibrated uniform depth, and (3) seed and fertilizer are covered and soil around the seed becomes compacted. This mechanical planter can sow 10–24 rows at once. The planter opens a furrow or trench in each row, drops the seeds in right amount, covers these seeds, and presses the soil on them (National Cotton Council of America).

29.4.3 Advanced/Modern Concept in Cotton Planting

Cotton is a source of raw material that mediates the quality of end product such as fiber. Cotton cultivation has been made obvious by the following unsustainable methods: extensive irrigation, mono-cropping, and excessive use of synthetic fertilizers. But now the trend has been changed toward sustainability (Radhakrishnan 2017). Many practices and programs have been started around the world to promote cotton production. Modern techniques have been developed regarding cotton sowing. Different sowing methods have been created for different environmental conditions such as environment-specific cultivar selection and invention of different implements for sowing (planter which maintains plant-to-plant and line-to-line distance, seed-cum-fertilizer drill).

29.4.4 Sowing Techniques Under Different Cotton-Based Cropping Systems

Cropping systems are defined as the sequences and management techniques of crops on a specific field over time (Goglio et al. 2018). Wheat-cotton-based cropping system is used in South Punjab, Pakistan; due to climate change wheat yield suffers after cotton harvest in wheat-cotton systems. Wheat relay cropping in cotton is an option to get maximum system profitability and wheat yield (Shah et al. 2016; Sajjad et al. 2018). Zero-till drill and manual broadcasting methods are used for relay cropping of wheat in cotton (Buttar et al. 2013; Nasrullah et al. 2017).

29.5 Modern Concepts in Nutrient Management

29.5.1 Soil Test-Based Nutrient Application

Maintaining soil fertility for intensive systems is important besides improving crop yield. The crops of intensive cropping systems use large amount of nutrients from soil during growing season (Kumar et al. 2017a, b, c). To overcome nutrient deficiency in the next cropping season, optimum fertilizer application is required. Fertilizers are the most costly inputs for nutrient application in agriculture, and their application should be rational and accurate (Kashyap et al. 2018). Soil testing is a unique technique to evaluate the soil health and fertility status for balanced fertilizer application. Soil test result and fertilizer recommendation interpretation is important to improve soil fertility status and crop yield.

29.5.2 Use of UAVs for Fertilizer Management

The use of UAVs/drones has been adopted in the recent decade consisting of high-resolution sensors and image processing unit which are reliable and cost effective for fertilizer prediction in agriculture (Daughtry et al. 2018). These drones have the capability to fly automatically to survey the crops from above for detailed growth observation (Wang et al. 2013; Guan et al. 2019). Schut et al. (2018) studied the fertilizer and yield response with UAVs and proposed that high-resolution images of UAVs can be useful to evaluate temporal and spatial variability of crop yield and crop yield response to fertilizers. Hunt et al. (2018) used a parafoil-wing UAV for colored-infrared images to assess the nitrogen status of potato (*Solanum tuberosum* L.). They reported that each treatment of applied nitrogen could be distinguished precisely in that image. Ballester et al. (2017) worked on assessing in-season nitrogen status and lint yield of cotton by using UAV images. They proposed that UAVs can monitor cotton nitrogen status variability at commercial farm and elaborate the challenges about information based on high-resolution images for fertilizer recommendation in in-season cotton crop at early growth stages.

29.5.3 Application of Sensors for Cotton Crop Management

Crop observations near the ground are an effective method which contributes a significant role in precision agriculture and agricultural production (Jia et al. 2014). These ground-based crop observations provide fast, nondestructive, real-time, and inexpensive crop growth information. On the basis of this information, the grower can increase yield by optimum and proper irrigation, fertilizer application, pest control, and harvesting on time (Li et al. 2009). Jia et al. (2014) worked on monitoring cotton growth and nitrogen status by using GreenSeeker handheld sensor to measure the canopy cover. They concluded that the relationships between above-ground total nitrogen content and canopy cover were precise and had an R^2 value of 0.926 and an RMSE value of 1.631 g/m^2. Sui and Thomasson (2006) reported that plant height and spectral information observed by sensing systems had significant correlation with N concentration of cotton leaf. Proximal sensor is also used for N status assessment. Commonly three proximal optical sensors (canopy reflectance sensor, fluorescence-based flavonol meters, and chlorophyll meter) are used for assessing N status in different crops (Padilla et al. 2018).

29.5.4 Vermicomposting

Vermicomposting is the procedure in which mesophilic bio-oxidation and stabilization processes of organic materials are introduced by microorganisms and earthworms. This will increase decomposition rate by changing stabilization of that organic materials and also modifying physical and bio-chemical properties (Lim et al. 2015). Lim et al. (2015) reported that vermicomposting can improve soil properties (physical, chemical, and biological). Soil treated with vermicompost has good porosity, aeration, water retention, and bulk density. Vermicompost contains macro- and micronutrients, enzymes, vitamins, antibiotics, and plant growth hormones. Nutrient balance depends on the C/N ratio present in vermicompost. The sources of vermicomposts are sewage sludge (Ludibeth et al. 2012), water weeds (Najar and Khan 2013), cotton waste of hospitals (Pramanik and Chung 2010), and animal manures. Rekha et al. (2018) studied the comparison between plant growth enhancer and vermicompost in *Capsicum annuum* L. crop. They concluded that plants treated with vermicompost exhibited significant growth than plant growth enhancer (IAA, GA)-treated plants.

29.5.5 Integrated Nutrient Management (INM)

The INM is a strategy for improving and maintaining soil fertility for sustainable crop production for a long period of time and reducing inorganic fertilizer cost

(Sindhi et al. 2018). Agriculture based on soil health and fertility ensures balanced and adequate nutrient supply to the plants. Vora et al. (2015) worked on INM effect on cotton and soil fertility after harvesting. They used ten different sources of nutrients which were fertilizers (organic, inorganic), gypsum, compost, castor cake, and vermicompost in their studies. They recorded that treatment under combined use of inorganic fertilizer, compost, castor cake, and bio-fertilizer returns highest yield of cotton as compared to control.

Reddy et al. (2017) studied the evaluation of INM interventions by using poultry manure and phospho-compost in cotton. They reported that lower yield is obtained from poultry manure-treated plots than phospho-compost-treated plots and also concluded that nutrient uptake by plants was improved in all INM interventions due to soil nutrient improvement. The soil organic matter and nutrient status continuously decreased due to intensive farming. The integrated utilization of organic and inorganic nutrient sources improves the crop productivity and fertility status of the soil.

29.6 Water Management Practices to Enhance WUE and Productivity in Cotton Crop

29.6.1 Consumptive Use of Irrigation Water

Over-exploitation of fresh water has been increased by twofold from the last decade to increase crop production and food security for the ever-increasing world population (Liu et al. 2009; Yuan and Shen 2013). This over-exploitation declining the ground water table will reduce the fresh water supply for crop production, which puts emphasis on using precious water resources efficiently (Pawar and Khanna 2018). Several strategies have been devised to enhance the consumptive use of irrigation water or WUE including varying sowing methods (Ali et al. 2017), lateral-move machines and center pivots (Roth et al. 2014), and models. Ali et al. (2017) performed field experiment on improving cotton yield by enhancing the WUE under different sowing techniques including flat sowing, ridge sowing, and bed planting at different locations in the province of Punjab. They found that maximum WUE (6.79 kg/ha/ mm) and SCY (3432.50 kg/ha) were obtained from flat sowing with earthing up on alternative rows.

Difallah et al. (2017) presented a linear programming model to determine the optimum amount of water required by the crop and the experiment was conducted in Algeria. They reported that this model could decrease about 28.5% of water consumption. Irrigating the crops with surface irrigation causes uneven water distribution, loss of water in the form of deep percolation, and seepage and also gives rise to weed growth. They suggested that sprinkler irrigation has high WUE and one can save water at about 30–60%.

29.6.2 Remote Sensing for Command Area Management

Remote sensing technique can provide automatic, continuous, and nondestructive information, which is easily implemented in data transmission systems to have real-time access to data collected from smartphone or a remote computer (Marino and Alvino 2018). Digital analysis is used to obtain information from satellite images; remote sensing is a dynamic, highly accurate data source to estimate irrigated areas as well as to monitor their evaluation based on time. Quebrajo et al. (2018) studied the irrigation management by using soil remote sensing and thermal imaging in sugar beet crop. Images were captured by thermal imaging camera on UAV for the evaluation of water and soil moisture status in sugar beet plants. They observed that sugar content and fresh root mass tended to be low when thermal imaging detected the water stress at a higher level.

Quantification of WUE in the field needs precise and high spatiotemporal resolution approximates of ET from the surface (Wu et al. 2009; Al Zayed et al. 2015; Ma et al. 2018). The irrigation requirement of crop can be determined by these factors: crop water requirement, soil water status, amount of rainfall, and efficiency of irrigation systems (Khanal et al. 2017). Studies explored the use of thermal remote sensing images in detecting the soil moisture status to facilitate irrigation scheduling (Khanal et al. 2017). Hassan-Esfahani et al. (2015) reported that use of thermal images can estimate accurately the spatial distribution of soil moisture at the surface in a Utah oats and alfalfa farm.

29.6.3 Irrigated Crop Area Monitoring

Generally 80% of fresh water is used in agriculture and it will be increased because of the ever-increasing population, and it is necessary to devise systems for sustainable water use (Pathan and Hate 2016). Identification of irrigated crop area is important for status monitoring, water management, and yield estimation (Wu and De Pauw 2011). For monitoring irrigated crop area, Internet of Things (IOT) techniques have been developed based on sensor information and they calculate the amount of water required. This system runs with two sensors to acquire data of soil temperature and humidity, temperature, and sunshine hours per day. This system is based on sensor values and estimates the amount of water needed for irrigation (Rao and Sridhar 2018).

Lepage et al. (2009) evaluated the SAMIR software used to estimate evapotranspiration and budget of irrigation water on a large scale, working on basis of satellite images. Remote sensing provides a synoptic view of crop development basic information for computing reliable evapotranspiration (ET) obtained from FAO method. Eunice (2013) introduced Zigbee network to monitor irrigation in paddy field. The architecture of this network is that different nodes are placed in the crop field. It calculates physical values such as pressure, temperature, water level, and humidity that can be observed in the field of paddy crop. The data observed from different places of the crop field is transmitted to GSM node, and then this data will be transferred to a personal computer through a gateway. A server which is connected to a database stores extreme values of water level, humidity, and temperature. If the sensors give data of extreme threshold level, the alarm unit produces a specific alarm sound to inform the farmer about the crop field.

29.6.4 GIS and Sensor-Based Irrigation

The reliable and timely monitoring and observation of water resources and exploration systematically and developing new techniques for irrigation water saving. To do this, it is important to use modern techniques of assessment, surveying, design, investigation, and implementation. GIS is considered as an effective tool for the management for irrigation water saving (Ali 2011). GIS is a system used to observe, store, evaluate, manage, and present data linked with different locations (Panwar 2015). Kamal and Amin (2010) studied the irrigation water management in rice by using GIS and developed a GIS-based water management model for scheduling irrigation water deliveries daily and regularly assessing irrigation water performance. The “scheduling” database computes the amount of water required by crop, and the “monitoring” database gives information about uniform distribution of water and deficit or excess. They suggested that GIS is an efficient tool to monitor irrigation water management in precision farming. Taghvaeian et al. (2018) assessed the irrigation performance in Southern California by using GIS and remote sensing. They implemented SEBAL to calculate actual ET in one irrigation and potential ET was assessed by Priestley-Taylor method. Remotely sensed data was integrated with ground data in GIS to compute several drainage and irrigation performance indicators. They concluded based on assessed data through GIS and RS that water consumption across the district was uniform and relative ET was high, showing that irrigation water supply was adequate.

Soil moisture sensors are being widely used for irrigation management in the last decade. A large number of affordable and reliable sensors are available working under the principle of FDR to calculate EC and VWC in soil (Montesano et al. 2015). These sensors when installed at different locations and multiple depths can give water status in soil profile. Computing the soil water tension as an active point for scheduling irrigation is an approach often used. Leib et al. recommended 30 to −40 kPa tension for irrigation threshold in sandy loam soils, and in silt loam soils, it was between −40 and −60 kPa. He also noted the important factors including site selection for sensor installation, sensor depths, and crop growth stages. Masseroni et al. (2018) studied the surface irrigation management by sensors in rice field. They used water-level sensor that provides enough data to regulate the inflow of water in real time and to cut off the water flow rate at a specific time.

29.6.4.1 Application of NDVI for Stress Management in Cotton Crop

Vegetation indices are used for the estimation of vegetation cover, and these indices are derived from satellite sensor data; among these indices, NDVI is commonly used to assess the vegetation spread area and quality (Vani and Mandla 2017). It was introduced in 1973 by Rousil; vegetation phenology is used in NDVI algorithm because green vegetation reflects more in NIR and less in visible light, while in sparse vegetation, reflection of NIR is less and a large portion of visible light is reflected. NDVI values are derived by combining these reflectance ratios (Vani and Mandla 2017). Stone and Bauer studied the irrigation management at variable rates by using NDVI to evaluate NDVI potential to estimate various crop coefficients for making spatial irrigation recommendations. They conducted a study on cotton irrigation under central pivot irrigation systems that compared the checkbook method (irrigation amount applied according to crop age and total weekly precipitation) with irrigation precipitation based on NDVI. Irrigation events were initiated through soil sensors. It was observed that irrigation amounts were different in the NDVI-based method from rates recommended by the checkbook method up to 70 days after sowing when NDVI value differences among field area and plant density were nonexistent. The results suggested that irrigation prescription based on NDVI method is warranted. Despite all of these, NDVI has some limitations to its application such as NDVI having same values for two different crop water conditions. Another fact is that NDVI readings may be influenced by errors inherent to the measuring technique; irrigation scheduling cannot be recommended at the moment based on NDVI value in one season study because it requires continuous study (Vani and Mandla 2017).

29.7 Improved Weed Management

The excessive weed proliferation in cotton decreases the cotton seed yield because weed would compete with cotton for nutrients, space, and moisture. Pre and post-sowing weed management is very important part among cultural practices, so it cannot be neglected. There are many improved methods that have been devised to control weeds including chemical and mechanical weed control, crop rotation, stale bed preparation, and many others.

29.7.1 Pre-sowing Weed Management

29.7.1.1 Use of Glyphosate

Glyphosate is the most extensively used herbicide around the world. The feature of broad-spectrum application makes glyphosate a prominent herbicide, and it can be applied at different times during the whole season. The positive impact of glyphosate herbicide has been observed in transforming agricultural practices regarding weed management in glyphosate-tolerant crops. The combined effect of a broad-spectrum herbicide such as glyphosate and crops tolerant to this specific herbicide allowed the use of efficient and simplified weed management that reduced the utilization of alternative technologies like hand and tillage weeding. Use of glyphosate herbicide before emergence of cotton reduces the weed management cost through chemical and labor costs. It is also promoted in the conservation tillage technique because it reduces mechanical weeding in cotton (Held et al. 2016).

29.7.2 Stale Seed Bed Preparation (SSB)

In stale bed preparation, a seed bed is prepared some days, weeks, or months before sowing of crop. Stale seed bed method allows the weeds to grow extensively before crop planting or sowing. After the extensive growth of weeds, they are controlled through early soil tillage or non-selective broad-spectrum herbicides. Tillage plays a role in controlling weeds by destroying the emerging weed seedlings, burying the seeds, and also delaying the growth of perennial weeds. This technique decreases weed emergence and early crop competition with weeds.

29.7.3 Mechanical Weeding

Mechanical weeding is the best reported non-selective method that is most effective in controlling annual weeds. It is the physical removal of weeds by using different tools including disks, hoes, rotary weeders, cultivators, and mechanical choppers. These implements are designed to uproot, cut, or cover weed seedlings. Mechanical weeding in cotton field can be done with primary or secondary tillage. Primary tillage such as moldboard plow is used for deep soil cultivation which leads to uprooting and shredding of weed flora growing in the cotton field before sowing. It also helps in burying a large quantity of weed seeds in a deeper layer of soil. Secondary tillage, for example, harrowing and disking, plays a role in shredding weed biomass. Both of this primary and secondary tillage destroy the weed biomass quickly in field, and follow-up with cultivator use may be important to uproot and dislodge the weed flora after tillage. Mechanical weed management in cotton field after sowing is more effective when weeds are smaller than cotton plants. Despite these, frequent use of tillage for mechanical weeding may lead to soil degradation, weed seed germination present near the soil surface, and perennial weed dispersal by breaking the vegetative structures present underground (Ashigh et al. 2015).

29.7.4 Transgenic Cotton

Application of various chemicals is needed for insect and disease management during the growing season of cotton. The SCY was severely affected by weed infestation in field crop. High weed infestation period is a few weeks after planting. When using herbicide, it is necessary to introduce herbicide-resistant cotton varieties. In 1997, a glyphosate-resistant cotton variety was used commercially resulting in a high yield of cotton (Latif et al. 2015). This new tool is also environment-friendly because it reduces the quantity and number of sprays during the whole growing season. Use of glyphosate in glyphosate-resistant cotton has non-residual, non-mobile, and less environment toxicity effect compared with residual herbicide. In glyphosate-tolerant cotton, weed management is easier than conventional method. But continuous use of same herbicide increases the resistance of weeds against this herbicide, and preventive methods should be adopted to reduce this rapid resistance in weeds. Farmers should also use some alternative herbicide for controlling weeds (Holtzapffel et al. 2008).

29.7.5 Use of Satellite Imagery for Specific Weed Management

Temporal weed monitoring is the first and primary step in site-specific weed management in cotton; using GIS, RS, and UAV, it is a technique in which careful mapping and monitoring of weed infestation in early growth stages is performed (Papadopoulos et al. 2018; López-Granados 2011). When the remote sensing system collects the reflectance from ground level, reflectance values from specific and individual features are used for average over the entire remote sensor pixel area. RS consists of low- and high-resolution pixels. In high resolution, images are explained through small pixels, while in low resolution, large pixels describe the reflected image (Clay et al. 2004). In weed monitoring strategy, two steps are involved: (1) weed map creation on the basis of frequent collected data and (2) weed detection in real time, integrating it with sensors, processing method, and actuation system. Despite these, this system also has some limitations including difficulty in weed detection at a very initial growth stage (Fernández-Quintanilla et al. 2018).

29.8 Modern Concepts in Pest and Disease Management

29.8.1 Plowing Practices

Reduced tillage practices can enhance insect pest issues because of previous crop residues left on the soil surface (Johnson et al. 2001). These crop residues provide food and shelter as host crops. Aphids and certain cotton insects might increase in areas where preceding crop residues are not incorporated at planting. Infestation risks can be reduced by employing herbicides before the planting of the next crop. When soil is disturbed for the purpose of preparing soil for planting, insect pests are exposed which are killed by natural enemies and/or because of lack of food. Reduced tillage practices increase the number of predators which plays a significant role in biological control (Gencsoylu and Yalcin 2004). Thus, plowing practices are considered the best strategies for controlling insect pests across the world.

29.8.2 Trap Cropping

Trap cropping involves planting minor areas nearby the protected crop with a crop that is susceptible to specific pests that will serve as an attractant and can be economically destroyed (Shelton and Badenes-Perez 2006). Specific plant species can influence associated insects by attracting them (Altieri and Nicholls 2004). The attractiveness of the trap crop causes insects to move to the trap crop and stay away from the major crop, leaving the major crop undisturbed.

Insects are major biological constraints in successful production of crops on a worldwide basis (Croft et al. 1985; Attia et al. 2013). Trap crops have been successfully used for suppression of insects across the world. Trap cropping has been used in China and the USA to conserve and enhance natural enemies of cotton aphid (Xia et al. 1998). In Egypt, basil crop is intercropped into cotton field as trap crop for the suppression of insect pests (Schader et al. 2005). In New Zealand, Rea et al. (2002) have studied and reported that trap crop, e.g., black mustard, was an effective control strategy against *N. viridula* in sweet corn. Trap cropping might be an effective approach to manage *N. viridula*. Sorghum has been used as trap crop against *N. viridula* adults positively in cotton fields (Tillman 2006).

The application of insecticides has played an important role in controlling insects, but their excessive use has many environmental issues (Ecobichon 2001). Trap crops can be an effective strategy for managing lygus bugs (*Lygus hesperus*) in the cotton field. Alfalfa planted in the cotton field can draw bugs out of the cotton field which will reduce the damage to cotton blossoms (Pedigo 1989). Inter-crops are very useful for suppression of insects as these crops provide a complex environment (Lal 2016). Thus, trap crops and inter-crops can be used for the suppression of insect pests in cotton crop production as sustainable approach.

29.8.3 Pheromone Traps

A *pheromone* is a chemical that is produced by an animal that changes the behavior of another animal of same species. The pheromones are used for the monitoring and control of insects because they perform important functions, e.g., mating disruption, mass trapping, attract-and-kill, and push-pull (Tewari et al. 2014).

Cotton is considered a well-known crop which is often attacked by many insect pests and hence consumes a large number of plant protection products (Deguine et al. 2008). Monitoring and control of American bollworm, spotted bollworm, pink bollworm, and *Spodoptera* can be done through the use of pheromone traps. Pheromones should be installed at a distance of 50 m from the field. Trapped moths are removed on a daily basis. Yellow pans and sticky traps have been used for the monitoring and control of whitefly in the field of cotton (mostly 25 yellow pans or sticky traps per one hectare).

Different types of sex pheromones have been used for different insect pests, and the most used sex pheromone in the adult moth of cotton bollworm (*Helicoverpa armigera*) is "D. Z11-16AL (97), Z9-16AL hexadecenal." It is also reported that sex pheromones (10E 12E)-10, 12 hexadecadienal for cotton spotted bollworm and Z7 Z11-16AC (50), Z7 E11-16AC (50) hexadecadienyl acetate for pink bollworm have been successfully used (Shah et al. 2011).

Gossyplure is a synthetic sex pheromone which has been significantly used against pink bollworm in monitoring and control of cotton fields. This pheromone reduced the population of larvae infesting cotton bolls because of disruption of premating pheromone communication between male and female moths (Henneberry 2007).

29.8.4 Application of Drones

Agriculture drones have been successfully used for spraying fertilizer and pesticides across the world (Kale et al. 2015). Crop spraying with the help of drones is up to five times faster than spraying with regular machinery (MIT 2016). As a drone can scan the ground and apply liquids quickly with great precision, this sophisticated equipment is considered well for the spraying of cotton crop. A cotton farmer can use drones to monitor a field for insects, disease, and other pests more efficiently compared to traditional scouting methods. Drones have a heat sensor which can detect hot spots in fields and quickly treat disease before the crop is lost.

The WHO estimated that one million cases were affected by manual spraying of pesticides in the crop field. The UAV aircrafts are used to spray pesticides to prevent health issues in humans. This laid the foundation to develop such technologies (drones) which reduce the wastage of chemicals into the atmosphere and water (Mogili and Deepak 2018).

29.8.5 Improved IPM Techniques

29.8.5.1 Cultural Methods

Cultural control is used to suppress pest population by making the environment less favorable for survival, growth, and reproduction of pest species. It includes the selection of cotton field, variety selection, crop rotation, deep plowing, and the time of planting. This method has been successfully used across the world. In cultural control, crop rotation is one of the best strategies for the suppression of soil-borne diseases and pests such as root-knot nematodes which are a well-known constraint in cotton production across the world (Starr et al. 2005). Use of resistant/tolerant varieties, avoiding excess nitrogen application, and destruction of crop residues are adopted strategies which can reduce the pest population into the cotton field (Singh et al. 2008). Early planting of cotton in the field is recommended to escape pink bollworm and American bollworm infestation (Draz 2009).

Sanitation of the field can be carried out through the cleaning of field equipment which is considered an important preventive control strategy of IPM. Different equipment (often ridger and drill) are used in the production of cotton. These equipment may carry many insect pests into the field. Use of clean and certified seed may prevent the introduction of pests into the field.

29.8.5.2 Biological Control

Biological control of insect pests is considered a sustainable approach in the suppression of multiple pests of cotton across the world (Tomson et al. 2017). *Trichogramma* species have been significantly used in reducing the bollworm population because *Trichogramma* species feed on 37–40% of the cotton bollworm eggs (Ba et al. 2008). In China, whitefly (*B. tabaci*) has been satisfactorily controlled through natural enemies (Shen et al. 2005; Naranjo 2009). In India, the use of neem products/neem-based pesticides and release of *Trichoderma* species have been used as a sustainable strategy in reducing the population of insect pests (Singh et al. 2008). *B. bassiana* has reduced the population of cotton plant bugs when it was sprayed on the cotton field (Tong et al. 2010). El-wakeil et al. (2006) stated that combined use of neem products and *Trichogramma* species is considered as the best biocontrol agent.

29.8.5.3 Mechanical Practices

The insect management techniques across the world are progressively leaning toward a more environment-friendly agriculture without upsetting the balance of an ecosystem (Tilman et al. 2002). Sex pheromone traps and light traps have been successfully used as mechanical methods in insect pest management across the world. Different types of traps have been widely used for the monitoring of insect pests such as yellow traps for aphid and white traps for thrips.

29.8.5.4 Chemical Control

Seed treatment shields seed or young seedling against pests and diseases transmitted by seed or soil and stimulates germination and plant growth. Seed treatment is an effective and economical control method for early-season insect pests in the cultivation of cotton. It can shield cotton seed and young seedling from insect pests, nematodes, diseases, and other threats to health and productivity of cotton crop. Various studies have shown that seed treatment is a sustainable strategy for controlling insect pests and diseases across the world. In the Mid-South, neonicotinoid seed treatments have provided significant harvest and economic profits in cotton production (North et al. 2017).

The effectiveness of seed treatment may vary from fungicide to fungicide, but treated cotton seed provides greater cotton yields (Copeland et al. 2016). Cotton seeds treated with the combination of polymer and fungicide give significantly higher seed quality parameters (Vijaya et al. 2017). In Brazil, seed treatment has been successfully used against bacterial blight and damping-off diseases in cotton production (de Medeiros et al. 2015). In India, seed treatment showed better results in the control of leaf blight of cotton (Sangeetha et al. 2018). Thus, there is a need to explore the significances of seed treatment at farm level because only a few use seed treatment at farm level due to lack of awareness.

29.9 Cotton Crop Yield Estimation/Forecasting

29.9.1 Use of GIS and Remote Sensing for Cotton Yield Estimation and Forecasting

29.9.1.1 Need for GIS and RS

It is very difficult to determine sample locations and measure a sufficient number of samples for the estimation of yield/biomass of cotton across the world. Moreover, the results obtained through surveying in the fields were not accurate (Zang 1998). Similarly, obtaining information about yield and biomass of cotton crop is a labor-intensive and slow process. Hence, there is a need to introduce new technologies which are cost effective and provide timely information.

29.9.1.2 Methodology

Remote sensing has gained much significance across the world as it has the potential and capability to provide spatial information at a global level on features and phenomena on Earth on a real-time basis. It is a very useful technology used for the estimation of crop acreage and production and is cost effective and timely (Gitonga 1995; Dalezios et al. 2001). RS techniques can offer a complete study of the surface of the Earth on a daily basis. It can be used for the estimation of net primary agricultural production over time and space. This can be attained by using vegetation indices; however, they are not a direct measure of productivity/biomass, but they are correlated with LAI and biomass (Todd et al. 1998). Remote sensing can detect the biophysical functions in the plant which provides a platform for the estimation of cotton yield (Dalezios et al. 2001).

There are four main ways by which remote sensing forecasts the crop yield and biomass. These ways are divided into four categories:

Remote Sensing Methods Based on Empirical Methods

In this method, spectral indices are calculated from satellite images such as NDVI which are indirectly used for the estimation of cotton yield and biomass.

Remote Sensing Methods Based on Water Consumption Balance Method

In this method, the whole growth period of cotton crop can be divided into different sets whose evaporation fraction is measured. This method estimates productivity as a function of evaporation fraction during crop growth and uses the water consumption balance model to estimate evaporation fraction.

Crop Growth Models

Crop growth models focus on complex interaction of physiological processes with the environment. Crop growth models are combined with spectral observation provided by satellite data. In this way, cotton yield and biomass are estimated.

Monteith Model

Remote sensing with the integration of Monteith model can forecast crop yield by using biomass. It is a simple and useful paradigm for modeling crop yield and biomass. This method can be successfully employed for cotton yield estimation across the world.

Table 29.1 Overview of some crop models and their impact on the study of cotton yield forecasting across the world

Crop model	Study location	Study impact	Sources
CROPGRO-Cotton	Pakistan	Positive effects	Wajid et al. (2014); Rahman et al. (2017, 2018)
Info Crop Growth	India	Results satisfactory	Hebbar et al. (2008)
CROPGRO-Cotton	India	Positive effects	Kumar et al. (2017a, b, c)
ARIMA	India	Positive effects	Debnath et al. (2013)
CROPGRO-Cotton	Georgia	Positive effects	Ortiz et al. (2009)
Semi-empirical	China	Positive effects	–
CROPGRO-Cotton	Georgia	Positive effects	Pathak et al. (2009)
CROPGRO-Cotton	Pakistan	Positive effects	Arshad et al. (2017)
CROPGRO-Cotton	Georgia	Positive effects	Hoogenboom et al. (2004)
CSM-DSSAT	USA	Positive effects	Jones et al. (2003)
AquaCrop	Spain	Positive effects	Garcia-Vila et al. (2009)

29.9.2 Application of Crop Models for Cotton Yield Forecasting

Being a major cash crop of Pakistan and due to its significant contribution toward the agrarian economy of a country, it is useful to know about production and productivity status of cotton in the future. One can utilize historical available data of production and productivity for predicting future production and productivity of cotton by using forecasting models (Table 29.1).

The CROPGRO-Cotton model can be used for simulation of growth and SCY for different weather, soil, and husbandry practices (Ortiz et al. 2009; Rahman et al. 2017). Several studies have been carried out regarding application of crop models across the world. Semi-empirical models were used for the prediction of cotton growth and SCY in response to various nitrogen fertilizers (Lie et al. 2009). Now many researches have been done on application of crop models for prediction of SCY in Pakistan (Wajid et al. 2014; Arshad et al. 2017; Rahman et al. 2018). Crop models have been used for the estimation of cotton yield under future climate to develop site-specific adaptation strategies for adjustment of sowing dates, irrigation, and fertilizer (Arshad et al. 2017).

CSM-CROPGRO-Cotton can be used for simulation of growth and yield of cotton for different weather and soil conditions and managing practices (Jones et al. 2003; Hoogenboom et al. 2017). However, a model was found to have the ability to evaluate cotton production for climate change situations (Murthy 2004). For prediction of crop development and yield, all models take different sets of parameters into consideration like cultivar characteristics, minimum and maximum temperature, solar radiation, and crop management's elements (Hoogenboom et al. 2017). Kumar et al. (2017a, b, c) have reported that CROPGRO-Cotton model can be run for the estimation of SCY, biomass, and LAI of cotton crop. Wajid et al. (2014) have used CSM-CROPGRO-Cotton model for the prediction of SCY and total dry matter. They have got satisfactory results for the different parameters of the cotton. Crop models have been satisfactorily used for the field-scale forecasting of crop yields and biomass for wheat, rice, and cotton in Pakistan (Bastiaanssen and Ali 2003).

Papageorgiou et al. (2011) have studied and reported that fuzzy cognitive map might be the convenient tool in the prediction of cotton yield and improvement of crop management. The ARMA and ARIMA models of forecasting of cotton and sugarcane yield have been used (Ali et al. 2015).

Crop area and productivity appraisal are an essential procedure in supporting policy decision regarding land use allocation, food security, and environmental issues. The ARIMA model has been successfully used in Asia. Debnath et al. (2013) used the ARIMA model for the forecasting of cotton production and yield in India. An AquaCrop model is a useful tool which is used for the estimation of cotton yield/biomass in response to water management. This model has been used to assist managers for making decisions in cotton irrigation under water-restricted conditions (Garcia-Vila et al. 2009). In India, the Info Crop growth models have been satisfactorily used in combination with RS and GIS for the estimation of cotton production in irrigated areas (Hebbar et al. 2008).

Future projections of climate change in cotton zone of Punjab, Pakistan, showed that there would be increases in temperature from 1.2 to 1.8 °C and 2.2–3.1 °C in RCP 4.5 scenario, while 1.4–2.2 °C and 3.0–3.9 °C increases are anticipated in RCP 8.5 scenario, for near-term (2010–2039) and mid-century (2040–2069), respectively. Similarly, rainfall variations are anticipated at −8% to 15% and −5% to 17% for RCP 4.5, while −8% to 22% and −2% to 20% variations are anticipated for RCP 8.5, in near-term and mid-century, respectively. SCYs are projected to decrease by 8% on average by 2039 and 20% by 2069 for RCP 4.5 relative to baseline (1980–2010). Mean SCYs are projected to decrease by 12% and 30% on average for RCP 8.5 (Rahman et al. 2018).

29.10 Modern Techniques in Cotton Picking and Storage

29.10.1 Mechanical Picking

Cotton mechanization is playing an important role in the life of farmers as millions of farmers are dependent on cotton crop directly or indirectly across the world (Deshmukh and Mohanty 2016). In the world, Australia, the USA, and Israel are the countries where all the cotton is harvested mechanically (Muthamilselvan et al. 2007). In Asia, this is somehow well adopted in India because it is the world's largest producer of cotton. Mechanical picking of cotton is a newly developed technology in Pakistan. Mechanical picking machines have become necessary to minimize the hard work involved in hand picking and save cost of production. Mechanical picking will enhance the production of cleaner grade of seed cotton. Machine picking increases fiber length and fiber strength when it is compared with hand picking (Tian et al. 2017). Further, the mechanical cotton picking system will also be helpful in

Fig. 29.1 Mechanical picking of cotton in Pakistan (**Source**: Central Cotton Research Institute (CCRI), Multan, Pakistan)

achieving timeliness of operation for the next crop. However, there are some issues to mechanical picking of cotton such as initial large cost of the imported mechanical pickers, management of homogeneous height of cotton plants, and lack of credit facilities. Mechanical picking of cotton improves the fiber quality and seed cotton uniformity (Khalifa et al. 2009).

29.10.2 Need for Mechanical Picking

There are many issues associated with manual picking such as it being tedious and costlier than other agricultural operations, non-availability of labor, and delayed picking causing yield loss and affecting the overall quality of lint. Farmers are finding difficulties to complete picking operation on time even after spending more money across the world. In Pakistan, late wheat sowing due to late picking of cotton is a major issue in cotton-wheat cropping system which causes significant yield reduction of wheat (Tahir et al. 2009). This indicates that there is urgent need of mechanical picking in the world to increase the economic value of the field. Pakistan has been importing cotton picking machines from Uzbekistan. Mechanical picker (Fig. 29.1). Cotton picking machines have been firstly imported by the CCRI to encourage innovation and mechanized farming in the country and enhance per-acre crop output to alleviate poverty in rural areas of the country.

29.10.3 Significances of Mechanical Cotton Pickers

Mechanical cotton pickers have a lot of significances:

1. These mechanical cotton pickers reduce the loss of lint yield left on the plant during manual picking.
2. These also reduce the cost of production of cotton crop and improve the quality of lint.
3. These cotton pickers have also reduced the yield reduction of wheat crop through timely picking of cotton lint.

Across the world, there is an urgent need to promote mechanical picking of cotton because it not only reduces the cost of production but it also fulfills the gap of labor shortage. Similarly, it reduces the risk of negative climate impacts on the cotton crop.

29.11 Emerging Technologies

29.11.1 Robots

Agricultural robots have been successfully used for seeding, harvesting, weed control, and chemical applications (Cariou et al. 2009) and for improving productivity and efficiency across the world (Foglia and Reina 2006). Agricultural robots have the ability to scout weeds present in the field, find open bolls in the field, pick cotton in the lab, improve fiber and seed quality, increase the value of markdown cotton, reduce weather risk, increase yield, lower harvest cost, and enhance cotton sustainability (Wang et al. 2008).

Various types of agricultural robots have been developed which perform different tasks in the field. Cotton is a crop which is more attacked by insect pests and diseases. Robots can be used to monitor and identify diseases in field during early stage. Newly developed robot (eAGROBOT) is used to detect diseases in cotton at an early stage using image processing techniques (Pilli et al. 2015). Similarly, soil-sensing-survey robots that use an electronic nose to determine chemical soil properties have been developed (Pobkrut and Kerdcharoen 2014). These robots can timely provide variability present in the soil fertility of a cotton field which is the most important approach toward increasing resource use efficiency. Haibo et al. (2010) established a wheat-seeder robot which utilizes an air suction precision seeding mechanism to precisely drop seeds using RTK-GNSS module. This robot can also be adjusted in seeding of cotton.

Robots can reduce fuel consumption and air pollution (Gonzalez-de-Soto et al. 2016). The conventional cultivation in which crops are conducted and managed manually can be improved by using intelligent machines such as robots (Xia et al. 2015). Many agricultural robotics based on visual guidance are developed for automatic operations in agriculture, like micro-dosing, de-leafing, and weed and insect management (Slaughter et al. 2008; Ota et al. 2007; Sogaard and Lund 2007). Labor shortage is the largest problem in the agriculture sector and very costly. Hence this sector demands for robots that are efficiently working (Bechar et al. 2015).

29.11.2 Computer and IT Applications

Information technologies, like radars, mobile/telephones, FAX machines, computers, satellites, etc., in the world contribute to numerous forms of information systems like IRS that help us in solving problems or making decisions. An IRS is an environment of people, technologies, and procedures that help us to find data, information, and knowledge resources that can be found in a specific library, for that particular matter, wherever they exist. These IT-based technologies are useful for cultivation of cotton. Amount of water sprinkled in a balanced quantity is also computerized. The production capacity of the farm has been increased owing to use of IT in agriculture. There are fewer losses as now work can be monitored by computer in a traditional field like agriculture, wherein we can boost yield and reduce the chances of errors.

29.11.3 Decision Support Systems (DSS)

Computer systems that offer users with provision to investigate complex information and help in making decisions are called DSS. These are information systems with a specific task to help people in the problem-solving and decision-making process. These systems consist of a collection of people, procedures, software, and databases with a purpose. In such systems, computer is the most important technology.

29.11.4 Precision Agriculture (PA)

PA is abstracted by a system approach to re-organize agricultural system toward a low-input, high-efficiency, sustainable agriculture (Cook and Bramley 1998). It has been used for the evaluation of how the small areas or plots have different production environments and yields in Asia (Farid et al. 2013; Chandel et al. 2014; Shivanna and Nagendrappa 2014). Precision farming of cotton has become the requisite of agriculture because of global warming, climate change, reduction in water resources, health hazards due to more application of insecticides and pesticides, and use of excessive amounts of fertilizers to meet the needs of the growing population. These problems can be handled by using fewer inputs, eliminating health hazards, and making the environment safer by lowering the use of insecticides, pesticides, and fertilizers. It becomes possible when we know about the potential of a specific land

and the composition of all nutrients necessary for better yield and soil water requirements.

This modern technology can be successfully applied in cotton farming by using computers, GPS, telecommunications, farm implements, GIS, machine guidance, and RS (Zhang et al. 2002). All these equipment coordinate with one another and make agricultural practices very easy and more input responsive. With the help of these modern technologies, precision farming is capable of collecting data regarding production variability in both space and time. This variability in the cotton field can be responded positively in proper time which is considered a major property of precision farming.

The VRA in precision agriculture is an area of technology that focuses on automated application of materials in a given field. Technology in which materials (fertilizers, chemicals, and seeds) are applied is based on data that is collected by sensors, maps, and GPS; hence this technology helps in accurate application of these materials into the field.

Map-based VRA adjusts application rate based on an electronic map. With the help of GPS and prescription maps, variable rate technology can measure the field position, and hence the concentration of agricultural inputs required by the cotton crop is changed as the applicator moves through the cotton field. There is no need for maps and positioning system in sensor-based VRAs. Sensors on applicator quantify soil properties or crop characteristics "on the go"; based on this continuous availability of information, a control system estimates input requirements of soil or plants and transfers information to a controller which makes sure there is availability of inputs to the location measured by sensors. This variable rate technology can be a sustainable approach toward enhancing the cotton production and decreasing the cost of production due to accurate application of all agricultural inputs into the cotton fields.

29.11.4.1 Significances of Precision Farming in Cotton Production

1. It decreases the bad environmental impacts of inputs used like fertilizers, pesticides, insecticides, etc. and the cost of production of cotton (Hedley 2015).
2. There is precise seeding in the fields by the seed drill controlled by the GPS system.
3. Spray nozzles having sensors shut down when there is no vegetation under the nozzles thus reducing the wastage of fertilizers and pesticides.
4. Auto-steer and sensors with GPS system ensure the automatic application of agricultural practices so farmers can work at night in the fields also.
5. Maps of the soil give all the information about the inputs to be supplied in the soil; hence farmers can apply nutrients more precisely and timely and can reduce wastage of nutrients (Srinivasan 2006; McBratney et al. 2005).
6. Satellite imagery provided by remote sensing can be used for the evaluation of requirements of different inputs.

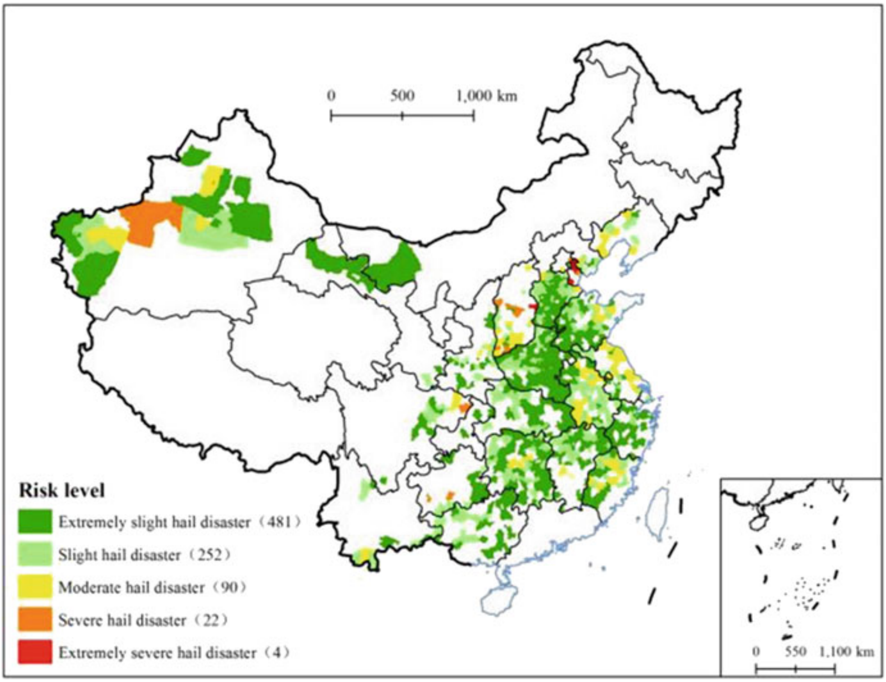

Fig. 29.2 GIS-based risk assessment of hail disasters affecting cotton and its spatiotemporal evolution in China (**Source**: Wang et al. 2016)

GIS technology has been successfully used for the management of cotton crop in China and many other countries of the world. In China, GIS was used for evaluation of hail disaster risk management to the cotton crop as shown in Fig. 29.2. According to this figure, Wang et al. (2016) have reported that hail catastrophe risk is low in China except for North China Plain and cotton-planting areas in Xinjiang Uygur Autonomous Region. Similarly, this technology can be used for many other special GIS-based risk assessments across the world.

29.12 Conclusion

The maintenance and improvement of soil quality, soil health, water quality, adequate water availability, and environment quality are the main challenges associated with sustainable cotton production. Hence modern concepts and technology applications in cotton production are crucial for the optimization of productivity and profitability and enhancement of resource use efficiency and sustainability with reduced environmental impacts. Innovations in cotton production are the need of the hour to meet the ever-increasing food and fiber demand of the ever-increasing world population. Modern concepts and technologies provide the basic tools to assess and manage the variability prevailing in different cotton-based cropping systems. Cotton crop is most sensitive to weather and other environmental stresses. Sustainable cotton production by efficient utilization of ever-decreasing resources and implementation of good management practices will maximize the productivity and profitability of cotton-based cropping systems. Precise use of resources in combination with modern technology is ideally appropriate to play a major role in sustainable cotton production. The application of modern technologies such as DSSs for crop management; the use of RS, GIS, GPS, and UAVs; wireless sensor-based crop monitoring and forecasting system; and agricultural machinery have key potential to enhance cotton production in a sustainable manner. Similarly, mechanical cotton sowing and picking, IT-based computer applications, and crop models can be used for sustainable cotton production.

Moreover, modern and innovative concepts such as X-ray spectroscopy and phosphorus-31 NMR spectroscopy for better soil sampling analysis and application of new tools such as MAS and MARS for better selection of genotypes have key roles in sustainable cotton production. On the other hand, modern concepts in seed testing and viability; minimum tillage concept for low GHG emission; new concepts in nutrient management; sensor-based fertilizer, crop, and irrigation monitoring system; and modern concepts in weed management can be used for successful cotton production across the world. Various types of agricultural robots can be used for precise seeding of cotton seed, weed control, and pest management and for improving resource use efficiency and cotton productivity. PA is a requisite of sustainable cotton production which can be used for the improvement of soil health, water quality, and environmental quality under cotton-based cropping systems. In conclusion, there is a need to adopt all the above-discussed modern concepts and technologies for the promotion of sustainable cotton production; conservation of soil, water, and other agricultural resources; and improving the environmental quality.

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