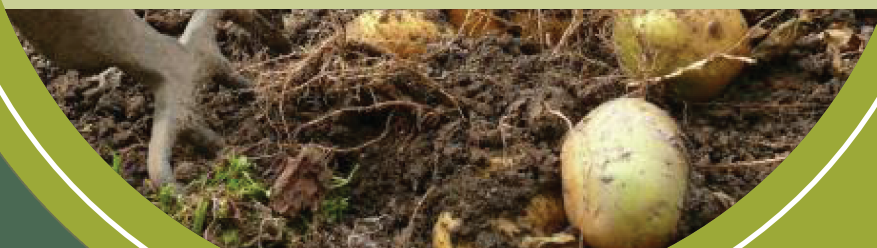


POTATO

Science & Technology for Sub Tropics



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Potato
Science and Technology for
Sub-Tropics

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Foreword

Potato is a staple food that contributes to the energy and nutritional needs of more than a billion people worldwide but has often been under-appreciated as far as its role in the global food system is concerned. It has a wide range of uses: as a staple food, animal feed, and as a source of starch for many industrial uses. The crop is ideally suited to places where land is limited and labour is abundant, conditions that characterize much of the developing world. Moreover, potatoes are a highly productive crop and produce more food per unit area and per unit time than field crops like wheat, rice and maize. Besides, potato cultivation and post-harvest activities constitute an important source of employment and income in rural areas, especially in countries like India. FAO has recommended that sincere effort should be made to realize the full agricultural potential of this crop in the Asian region. In recent past, remarkable progress has been made in potato production in countries like China (99 mmt) and India (52 mmt). The opportunities for further development of the potato industry appear to be very good in these countries. However, at the same time the problems to be addressed are substantial.

ICAR-Central Potato Research Institute, Shimla is internationally acclaimed for developing suitable varieties and technologies that virtually transformed the temperate potato crop to a sub-tropical one enabling its spread from cooler hill regions to the vast Indo- Gangetic plains as a *rabi* crop. It triggered a revolution in potato production causing very fast growth in area, production and productivity. However, the impact of global warming started manifesting during 1990s and it became imperative that further adaptation of potato from sub-tropical to more warmer growing condition would be necessary in near future to sustain its cultivation in the plains. The target of producing 125 million metric tonnes of potatoes in India by 2050 may appear to be unrealistic at first stance; however, analysis of factors and facts responsible

for future potato demand validate this big target. Nevertheless, this target is full of challenges that need to be addressed with focused research and development solutions during next three decades. This book on Potato Science and Technology for Sub-tropics deals with issues and strategies for varietal development, preparedness for climate change, bio-security & disease management, enhanced availability of quality seed and post-harvest management, besides emphasizing on the vision for potato crop in the country. I appreciate the efforts made by ICAR-Central Potato Research Institute in compiling this book, which shall disseminate the latest knowledge on potato crop to scientists, students and all the stakeholders so as to prepare them for the new challenges associated with this important crop.



(T. MOHAPATRA)

Dated the 7th January, 2020
New Delhi

Preface

Both potato production and consumption are accelerating in most of the developing countries including India and it is expected that the trend will continue for years to come. The two emerging Asian economies, viz. China and India together contribute nearly 1/3rd of the global potato production at present. Potato is preferred in these densely populated countries largely because of its high productivity, flexibility in terms of fitting into many prevailing cropping systems, and stable yields under conditions in which other crops may fail. Potato consumption in this region is increasing due to increasing industrialization and participation of women in the job market that created demand for processed, ready-to-eat convenience food, particularly in urban areas. There is a perceptible shift in food preference from cereals to vegetables and fruits. As per the projection made by ICAR-CPRI, Shimla, India would require about 125 million tonnes of potato annually by 2050. This enormous jump in production has to come from productivity enhancement, since availability of additional cultivable land for potato cultivation would be virtually nil due to unfavorable changes in land utilization pattern. On the contrary, plateauing of yield gain in potato has emerged as a roadblock for achieving productivity enhancement in a sustainable manner. Innovative technologies are immediately required for breaking this yield barrier.

Potato is a predominant vegetable in India. At present most of the domestic supply of potatoes is consumed as fresh (68%) followed by processing (7.5%) and seed (8.5%). The rest 16% potatoes are wasted due to post harvest losses. However, the proportion of potato used/ wasted due to various reasons is expected to change in the medium and long term scenario. In future, potato has to emerge from just a vegetable to a serious food security option. Considering limited availability of cultivable land in the country higher potato production has to be led by growth in productivity. Future roadmap of potato R&D would be primarily focused on enhancing potato productivity to 35 tonnes/ha by the year 2050. The second focus will be to improve quality of potato as desired by the industry as well as potato consumers in the era of economic development, higher purchasing power and willingness to pay more for the desired quality. Research on improved post-harvest practices will be targeted as another vital component.

For addressing the set goals on potato production and productivity enhancement, use of technological advancements is unavoidable. This book in its 20 chapters elaborates the latest scientific knowledge and technological achievements for development of potato in sub-tropics and also suggests the future strategies for likely adoption. It is our sincere belief that it would act as a compendium of potato research in the country and similar regions and researchers, students and other stakeholders will benefit from the compiled information in a big way.

Anand Kumar Singh
Swarup Kumar Chakrabarti
Brajesh Singh
Jagdev Sharma
Vijay Kumar Dua

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Precision Agriculture in Potato Production

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INTRODUCTION

Potato (*Solanum tuberosum* L.) is one of the major food crops which recorded total global production of 388.1 million metric tonnes (mt) in 2017-18. Out of the major staple food crops, potato production (388.1 mt) is exceeded only by maize (1077.98 mt), wheat (761.88 mt) and rice (494.88 mt) (FAOSTAT, 2017). According to the three years (2012-2014) averages, globally, India ranks 3rd in area and 2nd in terms of production next to China. The nutritional quality, high productivity and acquiescence for inclusion in intensive cropping systems of this short duration crop reflects its great potential in modern agriculture to feed the exponentially rising population in the developing countries. But, the intensive cultivation of potato crops urges increased use of fertilizers, pesticides and other chemicals leading to high input costs with plateauing yields. Blanket dose of fertilizers as well as imbalance use of nutrients not only increases the cost of farm inputs but also degrades soil condition and causes severe environment pollution. Indiscriminate use of insecticide as well as fungicide is very common in potato crop which contaminate the environment and deteriorate product quality. Therefore, the chemical inputs need to be optimised based on actual requirement of the crops for sustainable crop production. Furthermore, potato production is associated with a high tillage practices, number of tillage operation would depend on soil type, previous crop etc.

Precision Agriculture (PA) illustrate the strategic resource management to increase productivity and economic returns with reduced input cost. It utilizes advanced information technology tools to decipher spatial and temporal variability in soils, plants and surrounding environmental conditions within a field, which further integrate agricultural practices to meet site-specific requirements. Aim of precision farming is to uphold precision and accuracy while applying site specific farm inputs and as per requirement of the plants. Potato, being a high-value crop, holds a great opportunity for the implementation of PA due to the high cost of farm inputs used for various field operations such as seed, fertilizers, and agrochemicals as well as cost incurred in various field operations soil preparation, planting, harvesting, grading and handling. Furthermore, potato yield and quality are highly susceptible to crop management and environmental conditions with highly uncertain rainfall under the changing climate scenario. Hence, appropriate and on time application of inputs and resources is imperative to move up productivity at decreasing input cost and increasing profit.

In such situation, precision farming (PF) can help in in-situ specific and automated application of crop inputs to manage in-field variability resulting in increased yield with higher revenue. Précised application of input in potato results in not only lowering the input requirement and crop damage (*e.g.* reduced herbicide application causes less damage to the crop) but also increases the quality of produce leading to more uniform tuber size distribution with high specific gravity of tubers which may result in higher revenue in return. The United States Department of Agriculture (USDA) call this kind of agriculture ‘as needed’ farming and define it as ‘a management system that is information and technology based, is site specific and uses one or more of the following sources of data: soils, crops, nutrients, pests, moisture or yield, for optimum profitability, sustainability and protection of the environment’. It is a new management technology which uses geo-referenced information for the control of agricultural systems. It is based on the detailing of geo-referenced information through the application of monitoring processes and integration of characteristics of soil, plant, and climate.

TOOLS AND PROCESSES IN PRECISION AGRICULTURE

First step to proceed on path of PA agriculture is to assess the intra field variability in soil and plant with respect to desired parameter precisely and accurately (tagged with GPS location) followed by precise application of inputs based on measured variability. Various types of soil and crop nutrient assessment techniques have been developed. The conventional assessment of plant nutrient requirement can be determined by visual diagnosis of plants, plant and soil tests, nutrient omission plot technique etc. Water requirement of crop is assessed

by soil-water balance model, metrological data, by estimating crop coefficient, soil data etc. Disease and pest assessment in crop fields are done by monitoring the crop, diagnostic kits, counting the spores of the pathogen, ELISA, PCR etc. However, now in the precision agricultural technologies, proximal or remote sensors can be used to determine the spatial variability of soils and crops with improved efficiency. During the period crop is in field, the data are collected through sensing instruments such as soil probes, reflectance sensors like the Chlorophyll meter, the Green Seaker, the Crop Circle, the FieldScan, the Dualex etc.

Precision agriculture technologies involve various tools and techniques like GIS, GPS, variable rate applicator, UAV *etc.* First step to proceed on path of PA agriculture to assess the variability followed by precise application of inputs based on measured variability. Global positioning system (GPS) is being used for providing precise location coordinates. GPS is satellite navigation system gives continuous ground position information in real time. Having precise location information at real time allows soil and crop parameter measurements to be mapped, user can return to specific location for sampling or for application of inputs. GPS receiver with electronic yield monitors generally used to collect yield data across the land in precise way. Some of the uses in agriculture are - variable rate planting, variable rate fertilizer application, field mapping for records and insurance purposes and mapping yields. The data collection technologies are grid soil sampling, yield monitoring, RS and crop scouting. During crop production, the data are collected through sensing instruments and then recorded and stored in a computer system for future action and generated maps (using GIS) used for acquisition of information and for making strategic decisions (using DSS) to control variability.

Geographic information systems (GIS) which are used for generating maps are basically computer hardware and software that use feature attributes and location data to produce maps. An important function of an agricultural GIS is to store layers of information related to soil and crop. Geographically position can be added and mapped in GIS, this will help in easily viewing and analysis of data. Decision support system (DSS) are used to smoothen the decision-making process for management, operations, planning, or optimal solution path recommendation. These are software-based systems that gather and analyse data from a variety of sources.

Variable rate technology is considered core and heart of the PA (Figure 1). There are two types of variable rate technology for site specific application of inputs: map-based and sensor-based or real time based. However, both methods have their own advantages and limitations. The first site-specific management method *i.e.* map based method is the use of geo-referenced digital maps to

represent crop yields, soil properties, pest infestations, and variable-rate application plans. These geo-referenced digital maps have digital information about the particular soil grid in each pixel. Further these maps are integrated with the variable rate applicator. Whereas, in variable rate with real time sensing input is applied on real time basis.

Several studies have shown that use of site-specific variable input management strategies are capable to save input to a considerable level when compared with uniform management strategy and it has been concluded that, variable rate input application utilizing site-specific management are more cost effective and viable than conventional practices. Hence, it is evident that using precision agriculture technology leads to reduced use of input leading to reduced cost, improved output quality and quantity and reduced environmental pollution. This in turn helps in improving total factor productivity of agriculture farm.

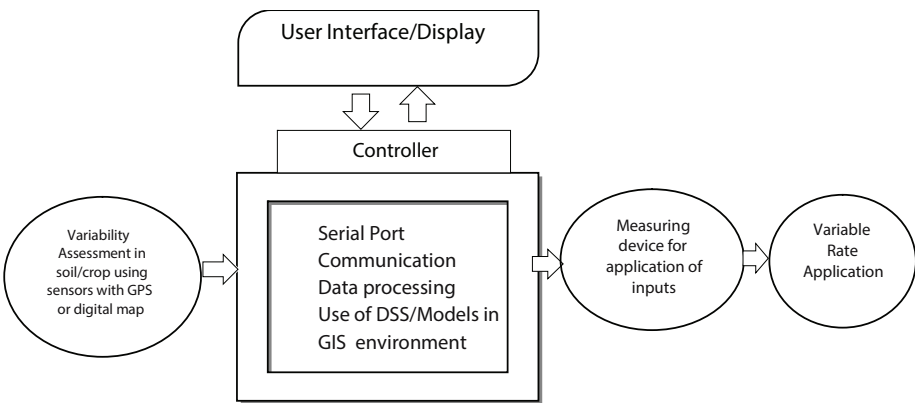


Fig. 1: Diagrammatic depiction of VRT approach.

Using Unmanned Arial Vehicle in PA

Airborne remote sensing technology is very useful to acquire high resolution images for spatial analyses of plant stress due to nutrients, diseases and pest infestation in the field. A high-resolution multispectral imaging system can be used with unmanned aerial vehicle (UAV) for variability assessment and site-specific application of the agro-chemicals. Main limitation of UAVs are their inability to carry heavy weight. However, an ultra-low volume variable rate aerial applicator could be used with UAV for low volume precise application of the chemicals. It could minimize the waste of inputs, increase input use efficiency, reduce health problem, reduce input cost and finally improves total factor productivity. Current uses of UAV in agriculture are in precision fertilizer

programme planning, weed and disease control programmes, tree and land mapping and crop spraying.

UAVs are being used in two ways-

Sensors and Visions

UAV is used for capturing images of the particular field or plant. Observation of individual plants, patches, gaps and patterns over the landscapes can be done which was not previously possible with traditional remote sensing techniques.

An UAV based image analysis software was developed for potato crop emergence assessment (Li *et al.*, 2019). High correlation was found between the image analysis and manual counting for plant emergence. Compared with traditional manual assessment, this new approach can save the time required to estimate crop emergence, average canopy cover and crop emergence uniformity.

Sprayer system

This system is used for site-specific pest management and vector control. Multi spectral camera monitors and scans the whole crop field and then generates a spatial map. This map illustrates the condition of the crop through normalized difference vegetation index (NDVI) and then the type of pesticides/fertilizers to be applied on the crop can be evaluated (Mogili and Deepak, 2018). The UAV system provides good spatiotemporal capabilities and when combined with appropriate electro optical sensors, it works more efficiently and accurately.

MAJOR APPLICATIONS OF PRECISION AGRICULTURE

Site specific application for nutrient management

Site specific nutrient application is one of the foremost components of precision agriculture. Research shows that fertilizers account for 30 to 70% of the yield. The variable rate application technology (VRT) for application of fertilizer is an important part of precision agriculture for applying fertilizers accurately as per demand of the crop and optimize productivity (Figure 1). Since, potato is a heavy nutrients feeder and these nutrients must be applied in such a précised manner and as per the crop demand that maximum nutrient reach to plant roots. This enables farmers to customize nutrient management according to the specific requirement of the crop and provides a framework for best management practices. Optimum fertilizer application plays a key role in improving the total factor productivity of various crops. Managing the land/crop within a field with different levels of input depending upon the yield potential of the crop and applying the fertilizer at required level results in reduced cost of production per unit area and reduced risk of environmental pollution.

Variable-rate fertilizer applications have been shown to improve efficiency and increase profits in many grower's fields. Profits is mainly in the form of increased yields without increasing total nutrient inputs or as sustained production at lower agriculture input quantity. Most of these systems consider both spatial and temporal variability, which can affect production. Most of the work in fertilizer application is focused on incorporating additional layers of real-time meteorological, soil and spatial information into the processes that can calculate fertilizer application rates. NDVI based N sensor is the most popular technique for on-the-go assessment of plant nitrogen. The NDVI is more concerned with the green index, basically reflectance of a crop canopy, which reflects the N variability in plants.

Koch *et al.* (2004) found that less total N fertilizer (6-46%) was used with the site-specific variable yield goal N management strategy when compared with uniform N management strategy and concluded that, variable rate N application utilizing site-specific management are more cost effective and viable than conventional practices.

Cambouris *et al.* (1999) conducted a 3-year trial to investigate the agronomic efficiency of VR application(VRA) of phosphorus(P) and potassium (K) fertilizers in potato production on a 2-ha field. In one year out of three, VRA of P and K significantly increased the total and marketable tuber yield compared with the uniform application of P and K. However, the effect of soil series on tuber yield was more significant and more consistent over growing seasons than the effect of application treatment. These more precise recommendations will help to ensure the success of PA approaches in potato production.

Chatterjee *et al.* (2015) in his work on management of soil nutrients with special emphasis on different forms of potassium considering their spatial variation in intensive cropping system of West Bengal, India concluded that the geostatistics-based mapping provided an opportunity to assess the variability in the distribution of native nutrients and other yield-limiting soil parameters across a large area. This could facilitate strategizing the appropriate management of nutrients leading to better yield, while ensuring a more effective environmental protection.

Site specific application for water management

Potato plants have sparse and shallow root system and hence very sensitive to water stress. Water requirement of the crop ranges from 350-550mm depending on the location, soil, variety *etc.* By using precision agriculture tools, site specific optimum supply of water as per the demand can be made efficiently.

A study conducted in province of Quebec, Canada, showed the spatial and temporal variability of soil water content and its effect on total yield (Allaire *et*

al., 2014). The authors found significant correlations between soil temperature, soil water content and total yield on a large scale and reported that low temperatures during the early growing season and lack of water late stage had a negative influence on yield. Precision agriculture in this case can be used to specifically supply water according to the initial water content of soil, which will help in improving input use efficiency and in turn total factor productivity.

Another emerging technology in the field of irrigation is variable rate irrigation. Modelling and soil sensors are being used to study water requirement in soil. Variable rate irrigation (VRI) is more advantageous as there is great variability found in soil texture in fields, excess or uniform irrigation may cause water and nutrient loss by runoff. In potato, it also deteriorates tuber quality. VRI includes different precision agriculture tools that facilitate a centre pivot irrigation system to optimize irrigation application. VRI technology allows growers to easily apply varying rates of irrigation water based on individual management zones within fields. Management zones are field areas possessing homogenous features for landscape and soil properties. These features lead to similar crop yield potential and input-use efficiency for seed, nutrients and water (Doerge, 1999). Control systems on center pivots allow the right amount of water to be applied to these management zones within the field.

Micro irrigation is commonly used technology for precise application of irrigation water. Water saving and productivity gains are higher in case of micro-irrigation as compared flood method of irrigation for the same crops. Micro-irrigation is also found to be reducing energy (electricity) requirement, weed problems, soil erosion and cost of cultivation. The on-farm irrigation efficiency of properly designed and managed drip and sprinkler irrigation system is estimated to be about 90 and 70 percent respectively. Studies conducted to compare micro-sprinkler, drip and furrow irrigation systems for potato has conclusively proven superiority of micro-irrigation. Economic analyses have also revealed microirrigation as a profitable alternative for potato production in semi-arid environment over the existing irrigation method.

Another approach for precise application of irrigation water is pulse irrigation. Pulsing irrigation refer to the practice of irrigating for a short period then waiting for another short period, and repeating this on-off cycle until the entire irrigation water is applied (Eric *et al.*, 2004). Under this technique water is applied to the plant in less amount with high frequency. Pulse irrigation helps in water saving by reducing runoff and leaching and by increasing water use efficiency in both heavy and sandy soil. Intermittent operation of sprinklers and foggers can provide evaporative cooling for temperature control. Smaller pipes and lower capacity pumps can be used which reduces the cost of irrigation.

PA for insect/pest/disease management

Potato crop is highly prone to incidence of insect and diseases and often heavy losses are inflicted depending upon growing situation and crop age. It is obvious that early pest and diseases can reduce yield loss considerably. If the symptoms are observed early, it might be corrected during the growing season. Since the objective is to reduce the spread of disease or pest to minimize production losses, this may be accomplished with monitoring and early detection. Application of agrochemicals is at present the most commonly used practice to protect plants from diseases, pests and weeds. In India, generally, manual or tractor operated uniform spraying systems are being used for insect/pest management. However, uniformity in these application systems depend on speed of operation and discharge rate of the liquid chemical. Therefore, speed based automatic flow control system could be a solution to maintain uniformity in application of the agro-chemicals. Different sensors are used for early crop disease detection, thus allowing a grower to adopt quick and timely crop protection (Table 1). As early as 1933, visible aerial photography was used to detect viral disease in potato. Seelan *et al.* (2003) used this imagery, flown low over potato, wheat and sugar beets to map numerous stresses on crops. In the high spatial resolution (70 cm) imagery wind damage, fertilizer skips and disease were visible.

Precautionary measures based on the meteorological conditions and precised application of pesticides and fungicides helped in reducing the one third of expenses. This reduction in input use improved the total factor productivity. Disease forecasting allows the prediction of probable outbreaks and decision support system can help in management of any further increase in disease intensity. This allows us to take strategic decisions about the disease management.

Late blight one of the most dreaded disease in the case of potato has been managed effectively using forecast models and DSS in terms of forecasting its appearance and management this has led to improve potato productivity and net return.

Table 1: Sensors for early detection of diseases and pests

Different methods of detection	Principle of Working
Pest detection sensors	Sensors provide real-time data from the field
Low-power Image Sensor	Wireless sensor which periodically capture images of the trap contents and sends them remotely to a control station. These images are used for determination of the number of pests found at each trap.
Acoustic sensor	Monitoring the noise level of the insect pests thus detecting the infestation at a very early stage.
Thermography Disease Detection Method	Captures infrared radiation emitted from the plant surface. It is based on detection of change in plant surface temperature.
Fluorescence Disease Detection Method	Measure changes in chlorophyll and photosynthetic activity, thus detecting the pathogen presence.
Hyperspectral Disease Detection Method	Measure the changes in reflectance that are the results of the biophysical and biochemical characteristic changes experienced upon infection.
Gas Chromatography Disease Detection Method	Determine volatile chemical compounds released by the infected plants.

INITIATIVES FOR DEVELOPMENT OF PA IN INDIA

In India, precision farming is still at a very budding stage. More than 86% of operational holdings are small or marginal size (< 2 ha) which is the biggest bottleneck in the practice of PF in India. Under such situations developing field specific recommendation of inputs is fairly good steps towards development of precision agriculture. According to a report, in the states like Punjab, Rajasthan, Haryana and Gujarat, more than 20% of agricultural lands have operational holding size of more than 4 ha, in such case intra-field variations can also be taken as input management options. Some discrete initiatives started towards the application of this technology. India–US Knowledge Initiative on Agriculture (KIA) has started working on PA in India in the year 2007. Tamil Nadu State Government sanctioned a scheme named “Tamil Nadu Precision Farming Project” implemented in Dharmapuri and Krishnagiri districts covering an area of 400 ha. High value crops such as hybrid tomatoes, capsicum, baby corn, white onion, cabbage, and cauliflower are cultivated under this scheme.

ICAR institutes Project Directorate for Cropping Systems Research (PDCSR) now ICAR-IIFSR, Modipuram, Meerut (Uttar Pradesh state) in collaboration with Central Institute of Agricultural Engineering (CIAE), Bhopal initiated variable rate input application in different cropping systems. In 2009, Space Application Centre (ISRO), Ahmedabad started experiments in the Central Potato Research Station farm at Jalandhar, Punjab, to study the role of remote sensing in mapping the variability with respect to space and time.

The Precision Farming Development Centres (PFDC) established in year 2001 play leading role in the development of regionally differentiated technology validation and dissemination. Presently, there are twenty-two (22) PFDC which have been established in India to promote precision farming and plastic-culture applications for hi-tech horticulture/ agriculture. The PFDC at IARI, New Delhi; University of Agriculture Sciences, Bangalore; Gujarat Agriculture University, Navsari; Indian Institute of Technology, Kharagpur and Central Institute of Sub-Tropical Horticulture (CISH), Lucknow function as Centres for excellence for Precision Farming (CEPF) and are equipped to take up research and development works on Precision Farming. The CEPFs function as mother centres for providing technical support to other PFDCs located in the region. ICAR Institutes and Institutes in the private sector are also involved in technology development. Recently, few start-ups have also come up to advise growers of cash crop on precision agriculture practices resulting into reduced cost of cultivation improvement in net income.

As an example of collaborative effort of private and Govt. agencies, precision farming centre has been established by MSSRF (M.S. Swaminathan Research Foundation – a non-profit trust) at Kannivadi in Tamil Nadu with financial support from the National Bank for Agriculture and Rural Development (NABARD). This Precision Farming Centre receives the help of Arava Research and Development Centre of Israel and works with an objective of poverty alleviation by applying PA technologies.

STATUS OF PRECISION AGRICULTURE IN POTATO CROP IN INDIA

When we talk in strict sense there is hardly any report on use of PA technique like VRT for the management of nutrient, water and pest in potato crop in India. However, there have been approaches to improve precision in recommendations based in field specific observation to optimise input application and yield enhancement. A decision support tool has been developed by ICAR-CPRI for providing information on the optimum time of planting and the likely consequences of early or late planting of potato in about 173 locations of Nilgiris region of Tamil Nadu state in India. This DSS developed for the purpose of potato crop scheduling is of great significance, which enables the farmers as well as extension functionaries for taking right decisions on timing the planting and harvesting of potato crop.

Spatial variability maps of available nutrients developed for potato growing pockets by ICAR-CPRI can also be tool to have nutrient recommendation specific to field than using a blanket recommendation for the region. These maps are useful for identifying specific locale of potato growing pockets with

different nutrient management problems. Further, the DSS developed for giving soil test based nutrient recommendations based on QUEFT model is a step forward toward precision. The quantitative evaluation of fertility of tropical soils (QUEFTS) model was calibrated for the estimation of NPK requirements for different targeted yields of potato. The results of the study showed that observed yields of potato with different amount of nutrients were in agreement with the values predicted by the model. Therefore, the QUEFTS model based NPK fertilizer recommendations can be adopted for site-specific nutrient management of potato. DSS has also been developed based on QUEFTS model to give soil test based field specific nutrient recommendation for different potato growing regions. Nitrogen is one element in potato cultivation for which in season real time decision on quantity and time of application is very important. Low cost tools like chlorophyll meter (SPAD) and leaf color chart (LCC) are simple, portable diagnostic tools that can be used for in situ measurement of the crop N status and proved to be useful for small farms of developing countries. Singh *et al.* (2019) worked on SPAD for in situ real time nitrogen management increasing number of splits of nitrogen (N) application is based on SPAD value. Through this technique it could be possible to save 10 to 20 % of recommended N without compromising on yield, thereby, improving efficiency and precision.

The only most important disease having maximum economic importance and requiring in season real time decision making in potato is late blight. Precision in the management of this diseases increased immensely with the development a Pan India computerized forecasting model 'INDOBLIGHTCAST', which is web based, to forecast late blight and the model could forecast the disease well in advance in comparison to other forecasting models tested. This has led to decreased number of sprays in several potato growing pockets.

Kumar *et al.* (2016) conducted the study to develop a decision support system (DSS) and integrated with soil moisture sensor based on tensiometric principle, for real time irrigation scheduling either on time basis or soil moisture sensor basis. The designed system was successfully tested on potato crop under different methods of irrigation at Precision Farming Development Centre (PFDC), IARI, and New Delhi, India. The reference evapotranspiration, water requirement of potato crop estimated from DSS was verified and tested with CROPWAT model, and approximately similar results were obtained. The performance evaluation of developed system helped to control water application as per crop needs with its various functionality were found satisfactorily.

These works are adding to help development of PA revolution in India directly or most probably indirectly. The need-based nutrient application for potato and application of DSS in Indian agriculture have been initiated in some places. To

utilize the full benefits of PA in Indian condition, an organized, well-planned, long-term policy suitable for Indian farming sector is required.

PRECISION AGRICULTURE FOR IMPROVING TOTAL FACTOR PRODUCTIVITY

In agriculture, people often misinterpret productivity as ability of a production system to produce more yield. But, the consideration of yield alone as a measure of productivity provides misleading indication of the degree of productivity improvement in agriculture (Chandel, 2007). There are many concepts of productivity but best-known concepts among them are partial productivity and total factor productivity. Partial productivity measures contribution of one factor/ input (say land, labour or capital) to output growth when other factors are kept constant. *e.g.* land productivity is measure of the land needed to meet food demands, like yield of crop per unit of land *etc.* However, it does not reveal whether increase in productivity is due to increase in use of inputs or increase in input use efficiency or due to use of improved technology. Further, it also ignores time, secondary products and inputs. Therefore, the other concept of productivity *i.e.* total factor productivity (TFP) has been found more relevant. It measures the ratio of total agriculture output to total production input *i.e.* output with the combined use of all resources and higher TFP indicates efficient use of agriculture inputs. That's why, it is regarded as accurate productivity measure. The best measure of TFP is to compare output with the combined use of all resources. Using PA technologies in potato cultivation can lead to increase in input use efficiency. Evert *et al.* (2017) reported that PA can lead to reduction in use of pesticide by 23% (expressed as EIQ) and nitrogen fertilizer by 15% in potato production, these results suggests that PA can improve total factor productivity. Rana and Anwer (2018) studied potato production scenario in India and analysed total factor productivity of potato production over the years. They found that the TFP have shown tremendous improvement and this change was mainly contributed by growth in technology change. Hence by implementing precision agriculture technology obviously we can improve total factor productivity making potato cultivation more efficient and profitable.

CONCLUSION

Potato being input efficient important food crop with future promise has great potential for use of precision agriculture. PA provides the ability to utilize crop inputs more effectively including farm equipment, seeds/seedlings, fertilizers, pesticides and irrigation water. With the growing concern of economic viability and environmental sustainability use of PA tools like GPS, GIS, UAV, models and DSS are likely to increase. It is likely that efficient and effective use of inputs would lead to greater crop yield and/or product quality, without polluting

the environment. However, the cost effectiveness of precision agriculture has not conclusively proven. Many challenges are there in the use of PA, like, lack of knowledge and technical know-how, poor connectivity in many areas, unavailability of high spatial resolution imagery for remote areas. In Indian scenario small landholdings appears to a major bottleneck to start with. Despite these challenges, with advancement in user friendly tools (apps, DSS, Models) and development of various types of cost effective sensors to capture minor variation of relevant abiotic and biotic parameters in soil and crop would lead to make this technology more usable and cost effective in coming days. Besides, with the improved availability of high resolution imagery from remote sensing and spatial analysis would provide valuable information by allowing complete understanding of the spatial complexity of the characteristics of a field and its crops, and providing information about the different parameters which in turn would be very useful in improving precision in input delivery leading to increased total factor productivity.

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POTATO

Science & Technology for Sub Tropics

Potato is a predominant vegetable in India and across the world however, the proportion of potato used/ wasted due to various reasons is expected to change in the medium and long term scenario. In future, potato has to emerge from just a vegetable to a serious food security option. Considering limited availability of cultivable land in the country higher potato production has to be led by growth in productivity. The main focus will be to improve quality of potato as desired by the industry as well as potato consumers in the era of economic development, higher purchasing power and willingness to pay more for the desired quality. Research on improved post-harvest practices will be targeted as another vital component.

This book in its 20 chapters elaborates the latest scientific knowledge and technological achievements for development of potato in sub-tropics and also suggests the future strategies for likely adoption. It is our sincere belief that it would act as a compendium of potato research in the country and similar regions and researchers, students and other stakeholders will benefit from the compiled information in a big way.

2020, 400 pages, figures, tables, 25cm

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