International Journal of Chemical Studies

P-ISSN: 2349–8528
E-ISSN: 2321–4902
IJCS 2019; 7(6): 2692-2696

Received: 18-09-2019
Accepted: 22-10-2019

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Tools of precision agriculture: A review

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Abstract
Today's polluted environment and over exploited natural resource, demand for immediate precautionary steps for sustainability of the earth. Agriculture also hugely contributes to such devastated condition. Precision agriculture technology is capable of performing site specific managements by delineating management zones. It helps achieve yield optimization, cost minimization and benefit maximization through GIS, GPS, remote sensing data acquisition, decision support system, sensor-controlled automatization, variable rate technology (VRT) and many other. For performing any management practice, the components work in concord. While GPS, remote sensors can provide location specific parameter values, GIS is able to create georeferenced wholesome map of a field; and controlled rate of chemical application is done through VRT via decision support systems. However, there are some of the factors which limits its adoption by the grower community over the world. But efforts are being made to improve adoption trend of precision-agriculture technologies; and make agriculture a sustainable practice.

Keywords: precision agriculture, VRT, decision support system, georeferenced

Introduction

The biggest concern of today's world with a human population of 7.7 billion, is clean water, breathable air and sufficient food to meet the food demand. The changing climate every year is creating uncertainties in production pattern from a piece of land so is creating concern about the food security. Arable land is getting shrunk day and pressure on the producing land is increasing at a faster rate. The per capita land of 0.23 ha which was in 2000 will get reduced to 0.15 ha by 2050 [24]. So, researchers are now trying to find a solution for the food as well as nutritional security for the humans by keeping an eye on the environmental sustainability as well. Prediction models are needed to be site specific to give accurate prediction data and give precise information on the benefit data. Improvement in crop yield by performing better in-field management decisions, reduction in chemical and fertilizer costs and more efficient application through information technology, permit more accurate farm records increase profit margin and can reduce pollution. Technology has a great role to play in such aspects. The techniques which are being collaborated with the advanced technology are Global Positioning System (GPS), Geographical Information System (GIS), operational control through Real Time Sensors and on the go sensors, remote sensors, telecommunication, mobile computation and advanced information processing models [14]. Precision agriculture has overall potential to help alleviate the problems those the future world is going to face. PA has the core concept of lowering input cost and increasing system efficiency through yield optimisation [40]. But according to Stafford (2000) [43] after years of development PA has reached at a crossroad where with availability of ample of technology, the environmental and economic benefits are yet to be proven. One of the reasons for lack of success of this technology is lack of awareness among the farmers about when and how to use PA in the fields. Not only research but also motivation to the farmers provided through in field demonstrations, establishment so also monitoring their efficiencies will be helpful to create a success story of PA technology in agriculture. The overall winning situation for PA technologies will have to be measured by economic and environmental gains [57]. This article provides information about the use of precision farming technologies in modern agriculture and the status of their development.

What is Precision Farming or Precision Agriculture?

According to literature meaning, precision farming means performing any agricultural management practice according to the status of the piece of land. It is considered as a concept, management strategy, and even a philosophy. PA basically creates the image of some computerised programmes which control the machineries via satellite signals or some local sensor setups which is able to predict crop development [47]. That is why it is also considered as the future of agriculture.

Scientifically, precision agriculture is a decision-making agricultural system based on the observed information, designed to improve the agricultural process through precise management of each step to ensure maximum agricultural production and continued sustainability of the natural resources [2, 41, 46] because it can provide timely and accurate information to the producer to make suitable management decision. As the PA works in converged approach with resource application, soil properties, agronomic practices, crop requirements, plant protection as they vary across a site, precision land managements are made easy and such information can be obtained through map-based approach or sensor-based information (fig.1) [2]. At the same time, the producer must understand that Precision farming cannot solely be characterised as use of high-tech equipment, but the acquisition and wise use of obtained information from that technology are the essential parts for obtaining optimum output from a piece of land.

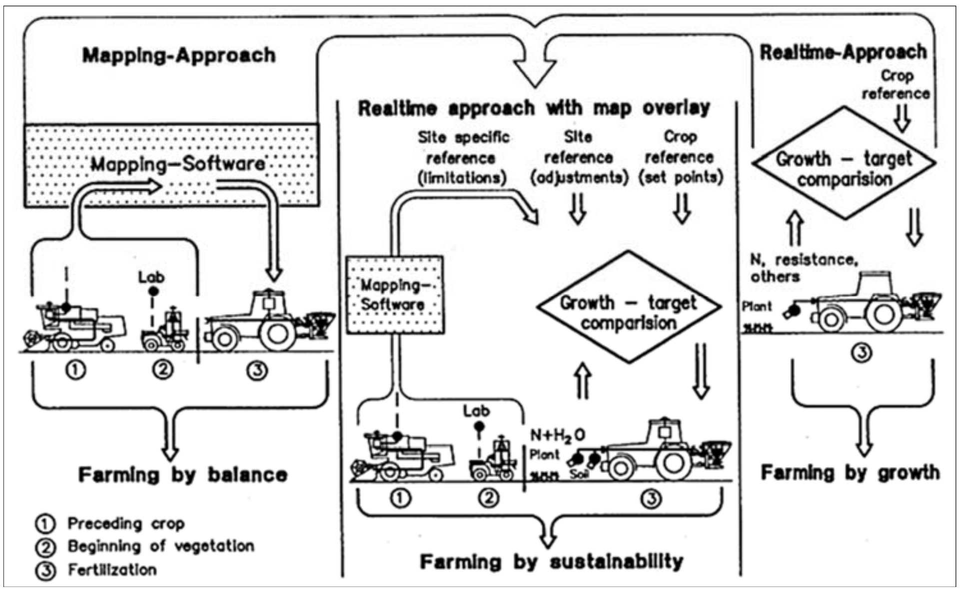

Fig 1: Systematic procedure for site specific input management technique

PA includes a huge number of advanced techniques which are divided into various categories according to the technological principle used in it. [22] has divided the PA techniques into diagnostic techniques which includes geo-referencing [30] yield monitoring, management zone and crop input determination approach [23]; and application techniques which includes laser land levelling, precision planting, precision water management, site-specific nutrient management, nitrogen dose management using LCC, SPAD, Green Seeker optical sensor, etc. [38]. Various tools are used in PA to perform the above-mentioned activities. So, the major tools of PA are Global Positioning System (GPS), geographic information system (GIS), miniaturized computer components, mobile computing, in-field and remote sensing, automatic control, advanced information processing, and telecommunications etc. [14]. But including GPS, GIS, Seelan *et al*. (2003) [37] has included yield monitoring devices, soil, plant and pest sensors, remote sensing, and variable-rate technologies for applicators of inputs in PA tools. So, GPS and GIS are the most essential tools of precision agriculture.

The sequential method of map-based approach includes receiving and recording of data about position of each soil sample and its parameter values through GPS receiver and a data logger; and ultimately a map is generated and processed along with additional layers of spatially variable information [1]. In short, the mapping approach is collection and storage of data in the system memory [2] which can be used for understanding fertility status of the location and go for balanced fertilisation [4]. For example, Corwin and Lesch (2003) [10] used dual-dipole EM-38 equipment for the detailed mapping of ECa and related soil properties at specified root zone depth intervals. While, to monitor actual growth conditions of the system over time, sensor-based approach is preferred [2]. In this method some soil sensors may be used to vary application rates in that site of the land in response to sensor output information in real time without a GPS connected to it [31].

Major Components of Precision Agriculture

1. Global Positioning System

As said before, in order to acquire precision in management, site specificity is the main concept to be considered in PA [34]. So, selection of land management practices and present status of that land goes hand in hand. Thus, geo-statistical interpolation method can describe the regionalized variables according to that the growers can make their decisions [17].

Global Positioning System as a satellite-based radio-navigation system (with a complete set of at least 24 satellites orbiting the earth in a designed pattern) maintained by the US Department of Defence (DoD) which provides accurate 3-dimensional location data (latitude, longitude, and elevation) data worldwide at any time, in any weather, available freely. There are two modes of GPS performance; single receiver mode which collects the timing information, timing is processed into position; and differential mode (DGPS) using two receivers of which one receiver is mounted in a stationary position and the other is on the machine/implement [23]. The transition of GPS to the next satellite generation and the European satellite navigation system Galileo is the improvement in the GP System [2].

Using GPS navigators, farmers can collect soil samples from a specific location in the field accurately, every year, to monitor crop conditions [35] so, the macro- and micro-scales spatial variability of soils [5,47,53] could be observed. Also, the complete architecture (field boundaries, acreage for field areas, roads, irrigation systems, distances between points and weed and disease affected areas [56]) could be generated by examining the agricultural land [46].

2. Geographical Information System

Geographic information system (GIS) is considered as the brain of PA [23]. For storage and handling of location specific data, GIS is essential [26] because it has the potential to analyse and process a large amount of data at high speeds. Also, time and money saving could be achieved by analysing remote sensing data and maps collected through satellite information systems for land cover land management simultaneously [28]. Some of the government agencies have made the data accessible on the internet [52] like U.S. Department of Agriculture (USDA) and European Union host Web sites which help the beneficiaries like farmers, businessmen and other development workers.

The technical method for studying variability aspects of a piece of land is through interpolation technique. Xiao *et al.* (2016) [52] have explained the spatial interpolations as 1. Geo-statistical interpolation which consists of Simple Kriging (SK), Ordinary Kriging (OK), and Universal Kriging (UK); 2. Deterministic interpolation which comprises of local polynomial interpolation [Inverse Distance Weightage (IDW), Planar Spline, Local Polynomial Interpolation (LPI)), Global Polynomial Interpolation (GPI), etc**.** Common interpolation methods used for soil variability maps are, e.g., kriging, cokriging, regression kriging, etc. [13, 18, 27, 36, 51] but the best fit is chosen from R^2 of the semivariogram [15] and cross-validation methods [29, 55]. Table 1 explains that out of the 7 types of interpolations

Table 1: The statistic of different process of groundwater interpolation.

Interpolation models	IDW	GPI	LPI	TSPLINE	OK	SK	UK
Root-mean-square (m)	0.90	1.45	1.08	1.24	0.30	0.23	0.47
R^2	0.88	0.86	0.89	0.89	0.92	0.98	0.95

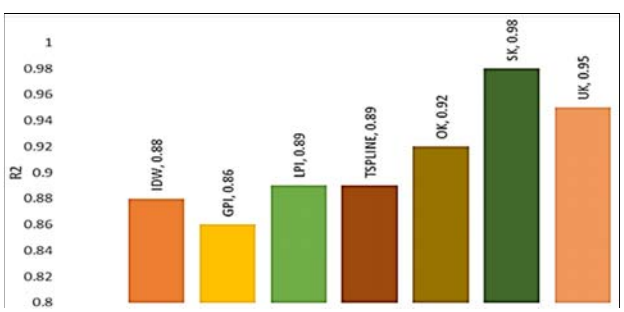

Fig 2: Comparison of regression coefficient of semivariograms of some interpolations for groundwater [51].

Where IDW= Inverse Distance Weightage; GPI= Global Polynomial Interpolation; LPI= Local Polynomial Interpolation; TSPLINE= Planar Spline; OK= Ordinary Kriging; SK= Simple Kriging; UK= Universal Kriging.

performed to study variability of ground water stratus of piedmont plains of north-west China, simple krigging is found to be the best fit with R^2 value of 0.98 [51]. Some of the other uses of spatial variability maps are to guide the agricultural inputs, such as water by studying soil profile water retention, bulk density, soil organic carbon value [36] fertilizer [16,41] pesticide, etc., for better management. GIS maps are helpful to evaluate environmental health also e.g. ambient air pollution study [48]. But if we look at the adoption rate of PA, though researches have started in the US, Canada, Australia, and Western Europe in mid-to late 1980s [56] still site-specific application of the fertilizers is the most accepted PA technology worldwide [57].

3. Remote sensing

Remote sensing (RS) collection of data is done by sensors which are placed on satellites or mounted on aircraft, by detecting the energy that is reflected from Earth. Remote sensors can be either passive or active. Passive sensors respond to external stimuli, most commonly the reflected sunlight from the earth's surface and records this natural energy while, active sensors use internal stimuli projected by the instrument itself to collect data about Earth. For example, in a laser-beam RS system, the sensor detects the laser (which has been projected by its own projector device) reflected back and measures the time of reflectance it takes for laser to reflect back to its sensor [49]. Yin *et al.* (2019) [55] have divided RS system components in to three broad categories namely spatial foundation system, ground base system and remote sensing data storage system which overall include carrier platform, remote sensor, control and positioning system, data transmission and data pre-processing systems.

Field studies and airborne scanner experiments have proved the strong correlation between spectral reflectance properties of vegetation canopies, soil and meteorological conditions [3, 37] so similar principle is applied for RS study in agriculture. Here the interaction of electromagnetic radiation with vegetation or soil is detected by capturing the reflected radiation emitted by either an active or passive sensor and measuring this captured radiation presents the status of the soil or vegetation attributes. The electromagnetic radiations used are usually visible, near infrared [32] infrared or microwaves and basing on them RS system can be classified into two main classifications: optical and SAR (Synthetic Aperture RADAR) [6]. Usually Landsat and Spot satellite images are used in precision agriculture [28].

RS has the ability to monitor the dynamic conditions of soil, plant, area under cultivation (with 95% accuracy), single crop cultivation area (within 10 days with 90% accuracy). The digitalized and georeferenced recorded observations are imported into the GIS workspace, delineations, maps, management zones are prepared to help the producer community in making decisions [46].

However, the essential features of RS for its successful adoption should contain frequent coverage, rapid data delivery, spatial resolution of 5-25 m, and integration with meteorological and agronomic data into expert systems as suggested by [21].

4. Variable rate technology (VRT)

Application of inputs precisely in variable type and quantity in different pieces of land according to the present status and requirement is the practice of variable rate technology (VRT) in PA [8]. For VRT, a multi-year analysis of one or more variables that influence or affect crop yield and also the yield values of the crop our interest is studied which as a result successfully creates management zones with its features well defined, management recommendations. This approach may be practised in either a weighted analysis or a non-weighted analysis of the variables affecting crop yield. However, the missing event history or data are the limitations of VRT and decision support system [20].

In VRT (variable rate technology) and VRA (variable rate applications), programmable machines attached with sprayers [9,39,46] are available to deliver the correct amount of chemicals depending on farm conditions like crop growth stage, crop condition and previously collected crop growth data. This part is responsible for lowering costs and reducing prejudicial to the environment by optimal application of chemicals [25]. Swinton and Lowenberg-Deboer (2001) [45] observed that though very beneficial, only USA and Canada have shown adoption of variable-rate fertilizer applications and yield monitors (using mainly GPS and GIS) at a rate of > 5% while Australia, Brazil, Denmark, United Kingdom and Germany have an adoption rate ranging from 1% to 5%, and these technologies are very rare rather quite unknown in Asia and Africa. But according to a study conducted by Nebraska Extension department throughout the year of 2015 for surveying the adoption rate of technology in farmer community of Nebraska, rate VRT adoption was found to be 68% [11].

Conclusion

There are tremendous benefits of Precision agriculture, still we cannot skip its limitations because they create the hindrance for its adoption in the practical field situation. Small land holdings, heterogeneity of cropping systems, high cost technology, lack of local technical expertise and knowledge like computer analysis and decision making are probably greater constraint in its success path because technological gaps seen in the farmer community is making them reluctant to rely on precision agriculture technology. But by overcoming these issues, we can positively use precision farming developments of today to create an environment friendly agriculture of tomorrow. Developments are going on for rapidly mapping insect infestations, disease spread pattern study via GPS and GIS receivers, variable rate spray operators are able to provide a permanent record of where and when the treatment took place back to the field manager by GPS data logger. Fleet management, field robots are some of the future technologies which are still there to be successfully implemented in agricultural fields.

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