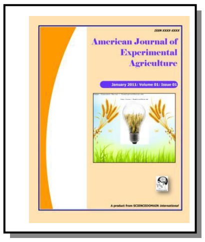

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Critical Review of Precision Agriculture Technologies and Its Scope of Adoption in India

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Review Article

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ABSTRACT

Precision agriculture (PA) concept was initiated for site specific crop management as a combination of positioning system technology, variable rate technology, remote sensing, yield mapping etc. to optimize the profitability, sustainability with a reduced environmental impact. From centuries Indian farms are experiencing some sort of soft precision agriculture technology. But the challenges of free and globalized market as well as ever-increasing population with huge food grain demand create the scope of adoption of hard precision agriculture technology in Indian farms. So learning the new agricultural technology invented in developed countries and its proper modification and application according to the domestic condition is necessary. Therefore, nearly hundred research papers generated in last three decades have been critically reviewed to find the status of main six components of PA, i.e., Positioning System, Remote Sensing, Variable Rate Technology, Crop & Soil Sensing & Analysis, Yield Mapping and Information Transmission Protocol. Additionally strategies for adoption of PA in Indian agriculture are discussed.

Keywords: Precision agriculture; GPS; remote sensing; yield mapping; VRT; Indian agriculture;

1. INTRODUCTION

To meet the huge food grain requirement of 480 million tonnes (Mt) by the year 2050, with increasing challenge of biotic and abiotic stresses experienced by crops, introduction and adoption of modern technology in Indian agriculture is inevitable. Agriculture, like other industries, has made entry into knowledge-based era, leaving its previous resource based

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nature. Future agriculture will be severely competitive, knowledge intensive and market driven. WTO agreement and liberalization of agricultural trade has not only created new scopes but also new threats to Indian agriculture (Mondal and Basu, 2009). Removal of quantitative restrictions on import form 1st April-2001, made quality and cost competitiveness as two most important factors to sustain in globalized market. Unlike the 'Green revolution' of India, which was supply driven, the future agriculture will be demand driven. The high cost of production and low productivity, even though we produce large quantity of yield, will throw Indian farmers out of the economic competition arena of free market (Kalkat, 2000). Again knowledge poverty, due to lack of timely start of research on advanced technology, is one of the main problem of developing countries. So to face all these new challenges, increase in the productivity level of pollution free product by application of advanced, environmental friendly technology, which can manage and allocate efficiently all resources for sustainable development of agriculture, is necessary (Mahapatra, 2011; Bhadoria, 2011; Basu, 2011). Precision agriculture is such a new emerging, highly promising technology, spreading rapidly in the developed countries. Precision agriculture is a scientific endeavour to improve the agricultural management by application of information technology (IT) and satellite based technology (e.g. global positioning system, remote sensing etc.) to identify, analyze and manage the spatial and temporal variability of agronomic parameters (e.g. soil, disease, nutrient, water etc.) within field by timely application of only required amount of input to optimize profitability, sustainability with a minimized impact on environment.

Farming in India is generally done by family responsibility system in small areas (1-4 ha), under the close inspection and supervision of farmer's family. So this close relation of farmer with crop and field made it possible for application of some sort of spatial treatment based on supervision and experience. But this crude precision agriculture technology is needed refinement and modification in the light of modern agricultural science (Mondal and Basu, 2009). Recent researches in 'Integrating farmer knowledge, precision agriculture tools, and crop simulation modelling to evaluate management options for poor-performing patches in cropping fields' can be very useful for country like India (Oliver et al., 2010).

Again in some part of the country, due to intensive production and mechanization in the latter half of the last century it was not possible to take care of the within field spatial variability. So these developed areas require advanced PA technology to be applied.

Advancement in space technology and IT revolution changed Indian environment and as well as created new scopes for farm sectors also. So under this changed condition it is necessary to grasp over the new cutting edge technologies in agriculture invented in the developed world and subsequent modification according to the domestic conditions for proper digestion of Indian farm sectors. It is true that the entire Indian farm sector is not ready to accept sophisticated PA technology. But like all other developing countries in India also there are some relatively developed areas which can act as incubators for new ideas and sophisticated technologies based on the domestic conditions (Maohua, 2001).

So the objectives of this paper are to review the state of PA technology in the developed countries and to find out the scope and future strategies for proper adoption of PA in Indian agriculture.

2. DEVELOPMENT OF PA TECHNOLOGY

PA technology is a combination of application of different technologies and all these combinations are mutually inter related and responsible for developments of main 6 sectors of PA, which are discussed below.

2.1 POSITIONING SYSTEM FOR PA

Positioning system works by the help of different constellations of satellites. Developments of these different positioning systems are the main technological milestone, which made PA concept a reality. Global positioning system (GPS), developed by US Department of Defense (DOD). Similar positioning system is Russian GLONASS positioning system. A European global navigation satellite system (GNSS), "Galileo" is under discussion (Spiller et al., 1998) and for that a 'definition study' funded by European Union (EU) and the European Space Agency (Stafford, 2000) is going on.

Each GPS satellite continuously broadcasts two radio signals on separate L band frequencies. Positioning system based coarse/acquisition (C/A) code of L1 signal is known as Standard Positioning System (SPS) and civilian users can use only this SPS (Pfost, 1998). After selective availability (SA) turned off, the dominant source of positioning error is the distorting effects of the earth's ionosphere on the signals from space. These effects will be minimized and the accuracy of the system further enhanced by the GPS modernization initiative, which will add another two civil signals at 1227 and 1176 MHz. Differential GPS (DGPS) can rectify the problem of digital noise with some limitations. But this differential mode of operation increases cost. Generally 12 channel receiver with phase smoothed pseudo range positioning system is used in PA. Sophisticated enough commercial receivers are now available at, a reduced price (hand held, 12 channel GPS receiver's price is less than £ 100) (Stafford 2000). All the position data should be stored and distributed from only one system, installed at a central vehicle (e.g. the tractor), for any task (Mondal and Tewari, 2007). The basic advantage of central system is that position data are calculated in accordance with the application and transferred directly to the point at which they will be used (Speckmann, 2000).

Kinematic GPS (KGPS) is more accurate positioning technology with centimetric accuracy, but not used in PA due to cycle ambiguity problem. Real time Kinematic (RTK) DGPS uses double differencing technique (Spilker and Parkinson, 1996) and can be used for detailed topographic mapping. The RTK technique can provide elevation accuracy of as good as 5 cm. This is possible because RTK systems extract additional information by examining the carrier wave of the GPS signal (Sudduth, 1998). One study has been carried out to know the Spatial Influence of Topographical Factors on Yield of Potato (*Solanum tuberosum* L.). High-resolution digital elevation model (DEM) data sampling was carried out with a RTK-GPS system. From the DEM, topographical parameters were extracted and topographical indices were estimated. The relationship of yield and the topographical parameters and indices was investigated and up to 20% of the yield could be explained in the final model for one of the fields (Persson et al., 2005). One study has been done to know the yield variability of Winter wheat (Triticum aestivum L.) related to landscape properties. Elevation and slope of the field were measured from a global positioning system (GPS) unit on the combine. Both were related to yield variability in the field. The study showed that high grain yield, straw yield and biomass could be related to flat, high places in the field with little erosion, whereas high straw yield and low grain yield were found at low places in the field on relatively steep slopes. Lowest grain yield, straw yield and biomass were located on steepest slopes with high erosion and in depressions where accumulation of eroded soil took place (Reyniers et al., 2006a). Synchronization of position information of field implement with the agronomic parameter map make possible the application of proper input matching with localized requirement of crop within the field.

It can be safely commented that positioning system technology used in PA is mature. Development of perfectly clear 3-D picture of ground terrain with ‘synthetic vision’ by the help of GPS will create scope of precision ploughing, irrigation etc. Farther improvement by the use of RTK DGPS, introduction of regional satellite positioning system by Quasi-Zenith Satellite

System, coupling of GPS with Inertial Navigation System (INS) will make positioning technology more robust, accurate and cheap.

2.2 REMOTE SENSING FOR PA

Remotely sensed data, obtained either by aircraft or satellite, containing electromagnetic emittance and reflectance data of crop can provide information useful for soil condition, plant growth, weed infestation etc. This type of information is cost effective and can be very useful for site-specific crop management programs (Plant, 2001). A lot of researches have been carried out for mapping weed in the field by remote sensing.

In a recent study, A SPOT 5 image acquired with four spectral bands (green, red, near-infrared, and short-wave infrared) and 10-m pixel size covering intensively cropped areas was evaluated for crop identification. Two subset images covering a variety of crops with different growth stages were extracted from the satellite image and five supervised classification techniques, including minimum distance, Mahalanobis distance, maximum likelihood, spectral angle mapper (SAM), and support vector machine (SVM), were applied to the 10-m subset images and the two coarser resolution images to identify crop types. The effects of the short-wave infrared band and pixel size on classification results were also examined. Kappa analysis showed that maximum likelihood and SVM performed better than the other three classifiers, though there were no statistical differences between the two best classifiers. Accuracy assessment showed that the 10-m, four-band images based on maximum likelihood resulted in the best overall accuracy values of 91% and 87% for the two respective sites. The inclusion of the short-wave infrared band statistically significantly increased the overall accuracy from 82% to 91% for site 1 and from 75% to 87% for site 2. The increase in pixel size from 10 m to 20 m or 30 m did not significantly affect the classification accuracy for crop identification. These results indicate that SPOT 5 multispectral imagery in conjunction with maximum likelihood and SVM classification techniques can be used for identifying crop types and estimating crop areas (Yang, et al., 2011).

Mapping of weeds against bare soil for row crops at early stages of seedlings has been carried out successfully. Depending on the principle that weed, bare soil and crop has different spectral signature, weed patches, in both 18 and 30cm row spacing, have been detected (Lamb, 1995). But mapping of weed is more challenging with full grown crops as there is a very little difference in spectral signature of weeds and crops in vegetative stage (Price, 1994). So spatial geometric effects of plants should be included along with spectral information to get proper result (Zwiggelear, 1998). As a general 'rule of thumb' for proper mapping of weeds resolutions of less than the minimum expected size of weed patch is required (Rew et al., 1997). But commercial available satellite images have spatial resolution of 36m (IRS - 1B), 30 m (Landstat TM) and 20 m (SPOT) (Campbell, 1996), which are not sufficient. Comparatively IKONOS has better resolution with 1 m panchromatic and 4 m multi-spectral with 1-3 day revisit time. Using IKONOS satellite imagery mapping of leaf area of vineyard, a key determinant of grape and wine quality, has been done. Derived NDVI data from these maps were converted to leaf area index (LAI) map, which showed potentiality to provide decision support for irrigation and canopy management (Johnson et al., 2003). Estimation of LAI spatial and temporal variation based on multi-temporal remote sensing observations processed using a simple semi-mechanistic canopy structure dynamic model (CSDM) coupled with a Radiative Transfer Model (RTM) improved the retrieval performances for LAI mainly by smoothing the residual errors associated to each individual observation for maize crop. In addition this method provided a way to describe in a continuous manner the LAI time course from a limited number of observations during the growth cycle (Koetz et al., 2005).

One study was made for estimation of sugar beet residue nitrogen by alternate satellite models (Beeri et al., 2005). 1 nm bandwidth spectroradiometer was used to take spectral reflectance to measure in situ leaf C and leaf N. These hyperspectral data were convolved to suit Landsat 5, SPOT 5, Quick-Bird 2, and Ikonos 2 multi-spectral satellite bands and models were created using stepwise linear regression. Mapping of average ground biomass was 80-90% accurate by this process. Synthetic Aperture Radar (SAR) images from satellite like ESR2 can penetrate cloud cover. So combination of SAR images with multi-spectral images can improve spatial crop management decision (Mondal and Tewari, 2007; Stafford, 2000). Ground penetrating radar (GPR) with 100 MHz surface GPR antennas was used to estimate soil moisture content (Lunt et al., 2005). Results of that study suggested that the two-way travel time to a GPR reflection along with a geological surface could be used to predict average water content over a large area, under natural conditions if borehole control is available and the reflection strength is sufficient.

One study has been made to investigate several methods for estimating tea quality based on tea quality data, near infrared spectroscopy and remotely sensed data (NDVI). Attention focused on two high yielding clones (TV1 and S3A3). NDVI was obtained from ASTER images. Statistical analysis shows that liquor brightness is affected by the levels of caffeine content, theaflavins and catechins. Relationships exist between quality parameters and remote sensing in particular for the S3A3 clone. NDVI has a positive relation with caffeine, theogallin, EC, and ECG. NIR is negatively related to caffeine, theogallin, and catechins. It was concluded that NDVI and Near Infrared (NIR) spectroscopy have a large potential to be used for monitoring tea quality in the future (Dutta et al., 2011).

Aerial Photography (AP) method has shown more promising result than satellite imagery method due to some benefits like operation below cloud, proper or intentional revisit time, higher spatial resolution etc. A charged-coupled-device (CCD) array camera mounted on a aircraft is used for discrimination of Yellow Hawk weed (*Hieracium Pratense*) and Oxeye Daisy (*Chrysanthemum leucanthemum*) (Lass and Callihan, 1997). Multispectral scanners (MSS), like Compact Air borne Spectrographic Imager (CASI) used from aircraft, can give pixel resolution of 1.8 m (Johnson et al., 1996) to 1 m (Portz et al., 1998). A study revealed that there was not much effect of compression of hyperspectral data sets acquired by CASI over corn fields, by the compression algorithm called Successive approximation multi-stage vector quantization (SAMVQ), when compared with the result of retrieval of crop chlorophyll content and leaf area index from decompressed hyperspectral data (Hu et al., 2004). A self-organizing map (SOM) neural network with an optimal Bayesian classifier, used for classification of plant and weed spectral properties, shown promising result (Moshou, 2001). Specific software and hardware like LARSYS imaging system has been developed to monitor different crop disease like corn leaf blight (Lamb and Brown, 2001). By using decision-tree technology identification of different fertilization method from hyper spectral images has been carried out with high level of success (Yang et al., 2003). For multi-spectral photography generally visible red (665 - 700 nm), green (555 - 580 nm) and NIR (840 - 900 nm) wavelengths are most useful as they can convey information regarding vegetation (Clevers, 1988). A herbicide application map of corn by using artifical neural network (ANN) and fuzzy logic proved potential for reducing water polluting from herbicide. During that study green-ness method, based on a pixel- by-pixel comparison of red-green-blue intensity values, was developed for identification of images of crop field (Yang et al., 2003).

Indices approach can enhance the capability of multispectral remote sensing for disease discrimination at the field level (Zhang et al., 2005). A 5-index image was used to identify late blight disease, caused by the fungal pathogen *Phytophthora infestans*, in tomato fields based on information from field-collected spectra and linear combinations of the spectral indices. This

5-cluster scheme successfully separated the diseased tomatoes from the healthy ones before economic damage happened.

One study has made to know the effect of water on nutrient stress (nitrogen, phosphorus and potassium) discrimination based on the visible and near infrared reflectance of maize leaves (Christensen et al., 2005). The study proved that prior knowledge of water status of plant can increase the ability to discriminate nutrient stress significantly. The study also proved that the knowledge of spatial location of leaves within a plant can be helpful to identify nutrient stress more accurately than whole plant behaviour (i.e., mean reflectance data from all leaves within a plant) (Mondal and Tewari, 2007).

One study has been done on wheat to compare aerial image with optical data of an on the ground platform multi-spectral radiometer. The NDVI of the ground system was better related to yield variables at harvest compared to NDVI of the aerial system. Best correlation coefficient found for both systems was with nitrogen in grain: 0.84 and 0.91 for the aerial-based and the ground-based system, respectively. Besides the higher accuracy in the estimation of yields variables, the ground system had the advantage of being cheaper and that the data were immediately available (Reyniers et al., 2006b).

Airborne Digital Photography (ADP) in recent days became famous with the fast development of digital camera technology. ADP technology is cheap, digitization friendly and overall having high resolution (sub-meter level). An Airborne Data Acquisition and Registration (ADAR) system has already been developed and used to map some specific weeds (Lamb and Brown, 2001). ADAR remote sensing data was used to detect rice sheath blight. Based on the field symptom measurements, a comprehensive field disease index (DI) was constructed to measure infection severity of the disease and to relate to image sampled infections. In addition to direct band digital number (DN) values, band ratio indices and standard difference indices were used to examine possible correlations between field and image data. A correlation coefficient above 0.62 indicated that these indices would be valuable to use for identification of the rice disease. In the validation analysis, a small root mean square error (RMS = 9.1), confirmed the applicability of the developed method. But failure to discriminate healthy plants from light infection ones due to spectral similarities confirmed the requirement of higher spectral resolution images for future studies (Qin and Zhang, 2005).

Zhang et al. (2011) presented a novel approach by constructing a spectral knowledge base (SKB) of diseased winter wheat plants, which takes the airborne images as a medium and links the disease severity with band reflectance from environment and disaster reduction small satellite images (HJ-CCD) accordingly. Through a matching process with a SKB, we estimated the disease severity with a disease index (DI) and degrees of disease severity. The proposed approach was validated against both simulated data and field surveyed data. Estimates of DI (%) from simulated data were more accurate, with a coefficient of determination (R 2) of 0.9 and normalized root mean square error (NRMSE) of 0.2. The overall accuracy of classification reached 0.8, with a kappa coefficient of 0.7. Validation of the estimates against field measurements showed that there were some errors in the DI value with the NRMSE close to 0.5. The result of the classification was more encouraging with an overall accuracy of 0.77 and a kappa coefficient of 0.58. For the matching process, Mahalanobis distance performed better than the spectral angle (SA) in all analyses in this study.

A new system has been developed for Real-time image processing for crop/weed discrimination in maize fields. The system consists of two independent subsystems, a fast image processing delivering results in real-time (Fast Image Processing, FIP), and a slower and more accurate processing (Robust Crop Row Detection, RCRD) that is used to correct the first subsystem's mistakes. This combination produces a system that achieves very good results under a wide variety of conditions. Tested on several maize videos taken of different fields and during different years, the system successfully detects an average of 95% of weeds and 80% of crops under different illumination, soil humidity and weed/crop growth conditions. Moreover, the system has been shown to produce acceptable results even under very difficult conditions, such as in the presence of dramatic sowing errors or abrupt camera movements. The computer vision system has been developed for integration into a treatment system because the ideal setup for any weed sprayer system would include a tool that could provide information on the weeds and crops present at each point in real-time, while the tractor mounting the spraying bar is moving (Burgos-Artizzu, et al., 2011).

In recent study, a method has been developed, using multispectral imagery and spatial pattern metrics to quantify stress to wheat fields caused by *Diuraphis noxia*. Multispectral images were acquired using an MS3100-CIR multispectral camera. *D. noxia,* drought, and agronomic conditions were identified as major causes for stresses found in wheat fields. Seven spatial metrics were computed for each stress factor. The analysis of spatial metrics quantitatively differentiated the three types of stress found within wheat fields. Detection and differentiation of wheat field stress may help in mapping stress and may have implications for site-specific monitoring systems to identify *D. noxia* infestations and help to target pesticide applications (Backoulou, et al., 2011).

Aerial photograph data, used to delineate management zones according to antecedent sugar-beat canopy colour, shown improvement in N-fertilizer management for next grown wheat crop (Sims et al, 2002). Leaves with higher nitrogen content have stronger spectral reflectance in blue and NIR wave bands and leaves with nitrogen stress, resulting in lower chlorophyll content, reflect more in red spectral region (Serrano et al., 2000). Effects of sensor and solar radiation variation are main source of errors and need to be properly calibrated. Errors due to variable illumination can be minimized by intensity normalization method, which is again having some inherent errors like loss of detail information. So compensation of the intensity variation, using relative reflectance by measuring the intensity at the time of imaging, would be a better way for of image calibration (Dasgupta and Michelewics, 1997).

Remotely sensed reflectance data are generally expressed in terms of different vegetation indices. Most commonly used Normalized Difference Vegetation Index (NDVI) is proved useful in estimating biomass and yield of some crops like wheat (Yuzhu, 1990). But NDVI has some limitations like it approaches saturation asymptotically under conditions of moderate-to-high aboveground biomass. Reflectance in the red region shows a nearly flat response if the leaf area index (LAI) exceeds 2. Whereas the near infrared (NIR) reflectance nicely responses to changes in moderate-to-high vegetation density (LAI from 2 to 6). This limitation had been overcame by introducing one weighing coefficient in Wide Dynamic Range Vegetation Index (WDRVI), which showed at least 3 times more response than NDVI when LAI value was within 2 to 6 (Gitelson, 2004). In case of weed map, developed by four-band airborne video camera, Soil Adjusted Vegetation Index (SAVI) proved more useful than NDVI (Lamb et al., 1999). Another type of useful vegetation index, Perpendicular Vegetation Index (PVI), uses red and infrared reflectance.

Although lot of experiments has been done till now, results proved that PA demands more resolution, accuracy and correlation among remotely sensed data and agronomic parameters. Spectral reflectance techniques for cereal are unlikely to be used for soil property analysis and for low population weed detection against a soil background due to some limitations, whereas same techniques can be one of the best options for crop canopy analysis (Scotford and Miller, 2005). May be in next decade more sophisticated, cheap, accurate remote sensing technology along with genetically engineered 'smart crop' can make justice to the demand of PA.

2.3 YIELD MAPPING FOR PA

Yield is ultimate indicator of variation of different agronomic parameters in different parts within the field. So mapping of yield and interpretation and correlation of that map with the spatial and temporal variability of different agronomic parameters helps in development of next season's crop management strategy. Present yield monitors measure the volume or mass flow rate to generate time periodic record of quantity of harvested crop for that period (Plant, 2001). Time periodic yield data is then synchronized with location address obtained from onboard GPS system to create most common color coded thematic map (Pierce et al., 1997). Different methods of mass flow measurement methods are being used (e.g. impact-plate method, dynamic weighing of trailor etc). Properly calibrated field monitor systems are generally very accurate (<1% to 5% error) at estimating yield averages over large areas (Pierce et al., 1997).

Instantaneous combine yield monitors generally provide good results if careful attention is paid during calibration, maintenance and as well as to manufacturer's instruction (Colvin et al., 1999). Contribution of deterministic structure in yield varied from 25-80% and the rest portion depends on stochastic structure and interaction between two. For design parameter optimization and modeling various stochastic modeling methods like genetic algorithm, artificial neural network etc. is used to predict yield potentiality (Bakhsh et al., 1998). Overlaying protein and yield for cereal crop has a significant relationship which was modeled using weighted regression with global and local neighborhoods in both 1-D and 2-D spatial location conditions. Both analyses showed that the relationships between protein and yield are significant at both the macro and the micro-scale level (Norng et al., 2005). Yield potential of corn was predicted and mapped using digital aerial color infrared (CIR) images by three methods, namely statistical regression modeling, genetic algorithm optimization and artificial neural network(ANN) with two image resolution of 3 and 6 m/pixel. Artificial neural network gave best yield prediction with error varying from 1.4% to 28% (Gopala Pillai, 1999). This study also proved that after pollination is a better time for yield prediction by using CIR images. ANN based yield prediction model for corn, using hyperspectral images acquired by CASI, showed better accuracy (about 20% validation RMSE) than three conventional empirical models based on normalized difference vegetation index, simple ratio, or photochemical reflectance index (Uno et al., 2005). Yield monitoring technology for grains is now an established technology. Market response of yield monitors is also very satisfactory in some markets, like north America, as the number of sold yield monitors rose from 50 in 1992 to 17,000 in 1997 (Lowenberg - De Boer, 1998).

In future, development of standard yield monitors for non grain crops is required. Further improvement by reduction of error from different sources like unknown crop width, the time lag of grain, inappropriate GPS recordings, yield surges, and other outlying values (Robinson and Metternicht, 2005) will make yield monitoring technology more precise.

2.4 SOIL AND CROP SENSING AND ANALYSIS FOR PA

Traditional extraction of soil sample and plant tissue sample and analysis in laboratory is time and cost intensive. In recent years many instruments have been invented based on direct contact and proximate remote sensing technology (Sudduth et al., 1997). Three instruments have already got widespread acceptance, namely infrared spectrometer, soil inductance meter and leaf chlorophyll meter. Plant water status can be determined by infrared spectrometer (Idso et al., 1982). Automatic registration of optical and IR images is a crucial step towards constructing an automated irrigation control system where plant water information is sensed via thermal imaging. In a recent study, the scene of the IR image is assumed to be completely included in the optical image and the alignment between the common scene in the two images may involve translation and rotation by a small angle, though a small scale difference may also be present. This automatic registration of data from two quite different, non-rigid imaging regimes presents several challenges, which cannot be overcome using common image processing techniques. In this paper, a fully automatic image registration algorithm for the alignment of optical and IR image pairs is described, where Pearson's cross-correlation between a pair of images serves as the similarity measure. A computationally efficient algorithm is designed and packaged as a software application. This work provides an intervention free process for extracting plant water stress information which can be fed into an automated irrigation scheduling program. The proposed algorithm is justified by the comparison of its registration performance with that of other potential algorithm techniques using several experimental data collections. Our results demonstrate the effectiveness of the proposed algorithm and efficiency of its application to the registration of IR and optical images (Wang, et al., 2010).

Diffuse reflectance spectroscopy can be a good alternative for conventional methods of soil analysis. This method has some remarkable advantages as it is rapid, timely, ‘on-the-go’, less expensive, non-destructive, straight forward and a single spectrum is sufficient for simultaneous analysis of various soil properties. One study showed that mid infrared (MIR) (2500–25,000 nm) was more accurate for predicting pH, lime requirement, organic carbon etc. than the VIS (400–700 nm) or near infrared (NIR) (700–2500 nm) due to the higher incidence spectral bands in this region as well as the higher intensity and specificity of the signal. The same experiment showed that NIR could produce more accurate predictions for exchangeable Al and K than any of the ranges (Mondal and Tewari, 2007; Rossel et al., 2006). Ground-based sensors were used to simultaneously monitor soil and canopy reflectance in the visible and near-infrared (VNIR) in a cotton field. The study showed that brightness values of the blue and green bands of soil reflectance were better correlated to soil water content, particulate organic matter and extractable potassium and phosphorus, while those in the red and NIR bands were correlated to soil carbonate content, total nitrogen, electrical conductivity and foliar nutrients. The correlation of red soil reflectance with canopy reflectance was significant and indicated an indirect inverse relationship between soil fertility and plant stress (Stamatiadis et al., 2005). Principal component analysis (PCA) technique was used to reveal spatial soil variation from near infrared reflectance (NIR) spectroscopy data of soil. Total carbon expressed a low spatial dependence with a high proportion of nugget, whereas clay content and pH expressed spatial dependence at a range of 54 and 46 m, respectively.

Recently wheat plants were analyzed using a hyper-spectral imaging system under laboratory conditions. Principal component analysis (PCA) was applied to differentiate spectra of diseased and healthy ear tissues in the wavelength ranges of 500–533 nm, 560–675 nm, 682–733 nm and 927–931 nm, respectively. Head blight could be successfully recognized during the development stages (BBCH-stages) 71–85. However, the best time for disease determination was at the beginning of medium milk stage (BBCH 75). Just after start of flowering (BBCH 65) and, again, in the fully ripe stage (BBCH 89), distinction by spectral analysis is impossible. With the imaging analysis method ‘Spectral Angle Mapper’ (SAM) the degree of disease was correctly classified (87%) considering an error of visual rating of 10%. However, SAM is time-consuming. It involves both the analysis of all spectral bands and the setup of reference spectra for classification. The application of specific spectral sub-ranges is a very promising alternative. The derived head blight index (HBI), which uses spectral differences in the ranges of 665–675 nm and 550–560 nm, can be a suitable outdoor classification method for the recognition of head blight. In these experiments, mean hit rates were 67% during the whole study period (BBCH 65–89). However, if only the optimal classification time is considered, the accuracy of detection can be largely increased (Bauriegel, et al., 2011).

The advantage of the NIR–PCA strategy is that the first PCs (PC 1) will capture the spectral bands that express the largest variation regardless of what the NIR bands correlate to and, hence, PC 1 will always explain the variation of the soil properties that in each specific case has the largest influence on the PCA model. NIR–PCA strategy seems to be an efficient and reliable strategy to use when determining the soil spatial variation in a field (Odlare et al., 2005).

By using optical sensor and photo-multiplier tube, real-time in situ sensing of photosynthetic activity of plant has been done (Kebabian et al., 1998). Plant nitrogen status can be correlated with the data obtained from chlorophyll meter (Miller et al., 1999). As cultivar and the growth stage significantly influence the sensor signal, they need to be considered when predicting the N uptake of the canopy using laser-induced chlorophyll fluorescence measurements (Schächtl et al., 2005). In addition to the leaf chlorophyll content, as an indicator of crop N status leaf content of polyphenolics can be used for the same purpose (Cartelat et al., 2005). Ion selective electrodes (ISE) have been used successfully for real-time sensing of soil nitrate. The major disadvantage of this system is the lengthy nitrate extraction process.

An effective technique to measure foliage chlorophyll concentration (Chl) at a large scale and within a short time could be a powerful tool to determine fertilization amount for crop management. A study has been conducted to investigate the inversion of foliage Chl vertical-layer distribution by bi-directional reflectance difference function (BRDF) data, so as to provide a theoretical basis for monitoring the growth and development of winter wheat and for providing guidance on the application of fertilizer. Remote sensing could provide a powerful tool for large-area estimation of Chl. Because of the vertical distribution of leaves in a wheat stem, Chl vertical distribution characteristics show an obvious decreasing trend from the top of the canopy to the ground surface. The ratio of transformed chlorophyll absorption reflectance index (TCARI) to optimized soil adjusted vegetation index (OSAVI) was called the canopy chlorophyll inversion index (CCII) in this study. The value of CCII at nadir, ±20 and ±30°, at nadir, ±30 and ±40°, and at nadir, ±50 and ±60° view angles were selected and assembled as bottom-layer Chl inversion index (BLCI), middle-layer Chl inversion index (MLCI), and upper-layer Chl inversion index (ULCI), respectively, for the inversion of Chl at the vertical bottom layer, middle layer, and upper layer. The root mean squared error (RMSE) between BLCI-, MLCI-, and ULCI-derived and laboratory-measured Chl were 0.7841, 0.9426, and 1.7398, respectively. The vertical foliage Chl inversion could be used to monitor the crop growth status and to guide fertilizer and irrigation management. The results suggested that vegetation indices derived from bi-directional reflectance spectra (e.g., BLCI, ULCI, and MLCI) were satisfactory for inversion of the Chl vertical distribution (Huang, et al., 2010).

A method of direct soil measurement (DSM) using ion-selective electrodes (ISEs) has been applied in a commercial implement for on-the-go mapping of soil pH, available potassium, nitrate-nitrogen and sodium contents. The coefficients of determination (R^2) of regressions between average DSMs and corresponding reference measurements were equal to 0.93–0.96 (soil pH), 0.61–0.62 (potassium), 0.41–0.51 (nitrate-nitrogen), and 0.11 (sodium). Results clearly depicted that although soil pH mapping was promising by using ISEs, further research on integrated on-the-go mapping of other soil chemical attributes was needed to investigate suitable application approaches (Adamchuk et al., 2005). Ion selective field effect transistor (ISFET) has been proved superior than ISE in several respects like high signal/noise ratio, fast response etc. The disadvantage of long-term drift and hysteresis of ISFET has been removed during dynamic measurements (Birrell and Hummel, 1993). Many experiments have been already proved close relationship between crop yield and apparent soil electrical conductivity (EC_a) (Lund et al., 1999). Terron et al. (2011) measured apparent soil electrical conductivity and geographically weighted regression was used to characterize the spatial variation in soil properties, which in turn can be used for soil management. This study showed that soil cation exchange capacity, calcium content, clay percentage and pH have a relatively strong spatial correlation with ECa in the soil of the study area. Surveys of EC_a are a quick, easy, reliable, and cheap ways of characterizing spatial variability of different type of physico-chemical properties of soil. But there are some limitations of this technique. Measurements of EC_a by themselves do not directly characterize spatial variability. Actually, EC_a measurements provide limited direct information about the physicochemical properties that influence yield, effect solute transport, or determine soil quality. Rather, EC_a -survey measurements provide the spatial information necessary to direct soil sampling. It is as a cost-effective tool for directing soil sampling that EC_a -survey measurements are invaluable for characterizing spatial variability. Furthermore, EC_a -directed soil sampling can only spatially characterize soil properties that correlate with and are measured by EC_a (Corwin and Lesch, 2005). EC_a can be measured either directly or indirectly. Generally, direct measurement of soil conductance are made by towing an electrode-equipped cutting disc through the field and indirect inductance measurements are done by taking point samples by hand-held device like non-contact electromagnetic induction probe (Plant, 2001). Generally indirect measurements provide higher sampling density at the cost of some errors in collected data. Sampling density can vary from one sample per few acres (grid soil fertility sampling) to one sample per 9 m^2 or less (on the go sensors) (Pokrajac et al., 2002). Traditional point sampling of soil is made on random basis and then averaged. But point sampling for PA requires specific methodology because here values of individual sample are correlated and interpolated to get contour map of soil nutrients of the total field. Regular grid sampling pattern is most famous for PA. Indeed, the most efficient pattern is an equilateral triangular grid (McBratney et al., 1981). Management of irrigation water, a critical input, precisely is another challenge for PA. Ultrasonic displacement sensor technology has been used successfully to quantify infiltration variability in furrow irrigated tomato field (Josiah et al., 1999). Using near infrared reflectance (NIR), soil moisture content prediction in laboratory condition resulted good results. But new calibration to correct difference in soil particle size variation required applying this method in field condition (Pelletier et al., 1996). Temporal stability model can be useful for explaining soil water variability (Starr, 2005). In this study a hammer-driven time domain reflectometry probe was used to measure soil water content. This temporal stability model explained 47% of the observed soil water content variability. Optoelectronic based soil organic matter sensor, using single wavelength as well as multiple wavelength sensor, has been developed. Multiple-wavelength sensor showed better flexibility for sensing soil organic matter using a single calibration than single wavelength sensor, which required recalibration for the soil and moisture content used at the time of experiment (Hummel et al., 1996).

Dynamic soil pH measurement, leaf fluorescence interpretation and correlation with crop status, use of biosensors for residual pesticide measurement in crop and soil (Maria, 2003), development of genetically modified crop, able to give proper and distinct indication of crop status, surrogate sensing and mapping etc. are few areas on which researches are going on to make analysis of soil and crop more accurate for PA.

2.5 VARIABLE RATE TECHNOLOGY (VRT) FOR PA

Existing field machinery with added electronic control unit (ECU) and onboard GPS can fulfill the variable rate requirement of input. Spray booms, spinning disc applicator with ECU and GPS have been used for patch spraying (Miller and Paice, 1998). During creation of nutrient requirement map for VRT consideration must be given on profit maximizing fertilizer rate (PMFR) than yield maximizing fertilizer rate (YMFR). Some research works showed that residual N calculation for only topsoil is not effective for some crops like corn, cotton due to high mobile nature of NO_3. For some soil, residual N at more depth (like 60 c.m.) as well as potentiality of N-mineralization of that soil during crop growth should be taken into consideration for N prescription map preparation for VRT application. Plant scale treatment by using spatial resolution, internal guidance and precision spray nozzles has already been achieved (Hague et al., 1997). Different types of error sources like GPS horizontal accuracy, DGPS horizontal accuracy, DGPS sampling frequency, machine delay times etc. has already been identified and should be taken care during VRT applications. One experiment showed that among all the above mentioned errors, machine delay and GPS horizontal accuracy were the most important error source (Chan et al., 2004).

Future research in VRT should be concentrated in development of 'true precision patch sprayer', equipment for land scale, plant scale and even leaf scale husbandry.

2.6 INFORMATION TRANSMISSION FOR PA

Type and amount of information collected and transmitted among different mobile and static electronic equipments used in agriculture are increasing rapidly which create requirement for standardized format for electronic communication. After an 11-year standardization effort, the German standard, the 'Landwirtschaftliches BUS - system' (LBS) is now available (Auernhammer, 2001). This standard was based on the controller area network data protocol (CAN; BOSCH, 1991), (Speckmann, 2000). Further need of globalized standardization of electronic communication used in agriculture gave genesis of ISO -11783 or commonly known as Agricultural Data Interchange Standard (ADIS). Drafts of the five part DIN 9684 (LBS) functions as a basis to develop ISO -11783 by ISO TC 23/SC19/WG1 (Technical Committee 23 - Tractors and machinery for agriculture and forestry, sub-committee 19 - Agricultural Electronics and WG1 - working group I). ISO 11783 relies on SAE J 1939 derived components for the basic communications structure with applications largely derived from DIN 9684 and some components of the standard are being developed within the working group I. Different components of ADIS are the Physical layer (Wiring and connectors consisting of 4 wires of which two will be used to carry data and rest two will provide power), Data link layer (Message structure is based on Controller Area Network (CAN) 2.0b 29 bit protocol), Network layer (Interconnection structure should provide normal bridge functions with additional filtering of unwanted signals), Addressing and naming and initialization, virtual terminal (operator-ECU interface), Task controlling (3 modes of operation - time, distance and position) etc. (Mondal and Tewari, 2007; Stone et al., 1999).

It is expected that ISO-11783 will make information transfer for electronic communication used in PA smooth and efficient between operator and equipment made by different manufacturers. But neither DIN 9684 nor ISO 11783 standard are complete solutions (Speckmann and Jahns, 1999). The concept of “smart transducer” is booming. Integration of a microprocessor with physical sensors/actuators and association of a signal conditioning/processing circuits can make a single, compact package—a “smart transducer” (Johnson, 1997). A common interface is required to be introduced for easy sensor/actuator integration, between transducers and other. Smooth information exchange is possible only if the transducer manufacturers and the transducer users follow the same standard. To date, there is no consensus among agricultural equipment manufacturers and transducer manufacturers about how to integrate transducers on agricultural machines. So farther improvement of ISO 11783 should include “smart transducer” etc. The IEEE 1451 smart transducer standards define connections between transducers and implement controllers whereas, ISO 11783 standard defines interconnections among different implement controllers. As PA technology advances, modular design, and plug-and-play capabilities have become a future trend that would be appreciated by sensor manufacturers, system integrators, as well as farmers. So, improved ISO 11783 standard, modified in light of IEEE 1451 standards, should provide a comprehensive solution for integration of embedded systems, complete plug-and-play capabilities for sensors, actuators, and implement controllers for system integration, designed to meet the challenges of future needs of PA applications (Wei et al., 2005).

3. SCOPE OF ADOPTION OF PA IN INDIA AND FUTURE STRATEGY

Adoption and success of PA in India will depend on the fact, that whether adoption strategies are designed properly or not. A planned numbers of experiments and analysis are required before application of PA to Indian agriculture. There are 3 steps to enter PA age, namely present stage, intermediate stage and future stage. Present stage involves uniform crop and soil management, development of specialist manpower and institution for PA, popularization of PA concept by mass media communication, seminar, workshop etc., whereas intermediate stage will follow stratified random sampling within zone, delineation of management zone throughout the country validation of computer models with zone specific data and future stage will involve fine grid sampling and sensing, application of zone specific computer model to simulate the agronomic input conditions and precise sensing and management (Mondal and Basu, 2009).

3.1 SCOPE OF ADOPTION OF PA IN INDIA

Precision agriculture can be classified into two categories, namely 'soft' and 'hard' PA. 'Soft' PA mainly depends on visual observation of crop and soil and management decision based on experience and intuition, rather than statistical and scientific analysis. Whereas 'hard' PA utilizes all modern technologies like GPS, RS, VRT etc. (Nowak, 1997).

Land fragmentation is considered as main obstacle for large scale agricultural mechanization in India. But these fragmented lands are cultivated in family responsibility system and all small farmers followed consciously or unconsciously 'soft' PA technology for centuries. By huge adoption of High Yielding Variety (HYV) crops, India at present producing nearly 200 Mt of food grain which made India self sufficient in food production. But only quantity cannot meet the need of globalized agricultural market. Quality as well as productivity will be key factor to compete with others. While in production India holds rank within 10 in most of the crops, in productivity of those crops the world ranking varies from 32 (wheat) to 118 (Cotton) (Sivanappan, 2002). Poor scale of mechanization with very small average holding size (1.57 ha in 90-91) with other reasons augmented the problem. Overall fertilizer consumption rate of India is small (84.3 kg/ha of arable land) in comparison to other countries (like China 266.4 kg/ha of arable land). Researches already showed that systematic soil testing followed by proper application of NPK fertilizer can increase productivity level 2-3 times in most of the states of India (Mondal and Basu, 2009; Siddiq, 2000). But high cost of traditional soil sampling is one reason of this improper application of fertilizer. So in these states cheap dynamic soil sampling technology as well as nutrient status analysis in large scale by RS can do a lot of improvement. But 96 million farms out of 105.3 million of total farm have less than 4 ha area. So for these huge numbers of farms Govt. steps to organize dynamic soil sampling and to create nutrient maps with the help of the already developed Information Technology are expected. Use of precisely validated zone specific computer simulation model can increase the span between two subsequent soil sampling by predicting intermediate conditions. These nutrient maps along with easy to understand fertilizer recommendation for each management zone within the field can be distributed from 'Panchayets' (Village regulatory body).

Again, some states, like Punjab, Haryana, have experienced the large scale mechanization as well as high doses of fertilizer and pesticide. For an example the state of Punjab has 1.5 percent of total geographical area of India, but uses 1.38 million tonnes (nearly 10% of all India fertilizer consumption) of NPK fertilizer along with 60% of weedicides used in India (Kalkat, 2000). Over exploitation of land as well as excessive use of agricultural input are typical problems of these areas (Bhadoria, 2011). So these areas are more or less suitable for 'hard' PA (Mondal and Basu, 2009).

Scope of adoption of any technology in any country not only depends on necessity, but also depends on the scientific environment of that country. History of Agricultural Research of India is old and rich. Large-scale soil testing in India has been carried out for decades and soil map of India on 1:1 million scales has been prepared and published. Already by adoption of perfected resource conserving technology, 20-30 % of water and N has been saved in some areas. India is one of the main participator countries in the 10 nations global rice genome project, completed sequencing ahead of time. Research is going on Integrated Plant nutrient system which already showed potentiality to increase input use efficiency by 20-30% (For further details readers are referred to THE HINDU, 16th July, 2003 pp.5). All these milestones are going to help the adoption of PA in India directly or indirectly. Indian Council of Agricultural Research (ICAR), one of the largest agricultural organizations in the world with more than 6000 scientists' power will be ideal institution to lead the PA revolution in India. ICAR, with a network of 47 institutions, 5 national Bureaux, 32 national research centres, 34 state agricultural universities and one central agricultural university and 344 KVKs (Agricultural Development Centre), has the enough strength to carry out the PA research in India.

But PA also demands some additional requirements like development of some PA organizations by bringing together researchers from different disciplines, Agribusiness and industry representatives, producers and others to develop outline as well as to carry out PA research properly.

3.2 FUTURE STRATEGY FOR ADOPTION OF PA IN INDIA

Future strategy for adoption of PA in India should consider the problem of land fragmentation, lack of highly sophisticated technical centres for PA, specific software for PA, poor economic condition of general Indian farmer etc.

'Virtual land consolidation' while keeping ownership structure intact can be a solution of land fragmentation problem of India and can create new roads for PA. Initial analyses of existing 'transborder farming system' show a saving of 15-25% in required head land, 20-30% in required work time and good amount of total operational cost savings (Auernhammer, 2001).
Another possibility of introduction of PA in small farms is that individual farms will be treated as if they were management zones within a field and that some centralized entity will provide information to the individual farmers on a co-operative basis (Plant, 2001). The problem of high cost of positioning system for small fields can be solved by 'dead reckoning system'. The dead reckoning system, suitable for small regularly shaped fields, relies on in-field markers, such as foam to maintain consistent application. (Monson, 1997).

'Integrating farmer knowledge, precision agriculture tools, and crop simulation modelling to evaluate management options for poor-performing patches in cropping fields' can be an excellent option for country like India. A recent study showed that (1) farmers have good understanding of the spatial extent and rank performance of poor-performing areas, when compared to NDVI or yield maps, (2) there is a wide range of physical and chemical soil constraints to crop yield in such patches, some of which can be ameliorated to raise yield potential, and others where crop inputs such as fertiliser can be better matched to low yield potential. Management options for poor-performing patches were evaluated through simulation analysis by removal of constraints to rooting to varying extents, and hence plant available water capacity. These examples show that if the constraint is mis-diagnosed then the potential benefits from amelioration can be overstated. In many cases constraints, often associated with physical limitations such as shallow available rooting depth or light-texture cannot be ameliorated or are uneconomic to ameliorate. In such cases the best intervention may be to lower crop inputs to better match the water-limited yield potential of such poor-performing areas. This research integrated farmer knowledge and spatial data to define yield zones in which targeted soil sampling and crop simulation were then used to determine yield potential and particular constraints to that potential. The economic costs and benefits of differential zone management were examined under a range of husbandry scenarios and, importantly, the sensitivity of economic gain to mis-diagnosis or errors in defining the zones was tested. This approach provided farmers with a robust and credible method for making decisions about spatial management of their fields (Oliver et al., 2010).

A nationwide Agricultural Advanced Technology (AAT) program should be started immediately for next 10 years. The scope of application of already developed Information Technology and satellite-based technology in the agricultural field should be studied. Trial farm projects for PA should be started region wise. Nature of crop and weed vary from zone to zone, country to country. So development of software and hardware for crop and weeds of India, site specific tillage technique, etc. should be started and these packages will be used for PA (Mondal and Basu, 2009; Bhangale and Mondal, 2011; Tewari and Mondal, 2011). 200 Agricultural Advanced Technology Park (AATP) should be developed in each region throughout the country which will gather experience and develop methodology to apply PA precisely in region wise format within the country (as an example China already developed 153 no of such parks (Maohua, 2001)). These AATP can work as embryo of new region wise PA technology as well as incubator of mature technology already developed in developed countries.

Adoption of PA in India is likely to follow classical S curve pattern (Lowen berg - De Boer, 1998). Attitudes of confidence toward using the precision agriculture technologies, perceptions of net benefit, farm size and farmer educational levels positively influence the intention of farmers to adopt precision agriculture technologies (Adrian et al., 2005).

4. CONCLUSIONS

This century is the century of biotechnology and Information technology revolution. Future Precision Agriculture will be an offspring of these two technologies with a rich heritage of relatively old, satellite based technologies of last century. PA has created scope of transforming the traditional agriculture, through the way of proper resource utilization and management, to a environmental friendly sustainable agriculture. Application of artificial neural networks, genetic algorithms, fuzzy logic, wavelet techniques, decision tree, smart microprocessors, genetically engineered plant, biosensors along with other future development areas already discussed will make PA not only suitable for developed countries but also for developing countries, if applied properly, and can work as a tool to destroy the distance between developed world and the rest.

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