RESEARCH ARTICLE

MANAGEMENT OF SOIL SYSTEM USING PRECISION AGRICULTURE TECHNOLOGY

Aakash Mishra[1], Pawan Kumar Pant[2], Pallvi Bhatt[3], Padam Singh* and Poonam Gangola[4]

[1]Department of Soil Science & Ag. Chemistry, BACA, AAU, Anand, Gujarat- 388 110
[2]Soil and Land Use Survey of India, Department of Agriculture Cooperation &Farmers Welfare, New Delhi, 110 012
[3]Department of Soil Science, G.B.P.U.A. & T., Pantnagar, U.S. Nagar, Uttarakhand,263 145
[4]College of Forestry, Ranichauri, Veer Chandra Singh Garhwali Uttarakhand University of Horticulture and Forestry, Tehri- Garhwal- 2491199
Email: aks_soil85@rediffmail.com

Received-05.02.2019, Revised-26.02.2019

Abstract: To maximize the productivity from the limited natural resources on a sustainable manner, the only way left is to increase the resource input use efficiency. It is also certain that even in developing countries, availability of labour for agricultural activities is going to be in short supply in future. The time has now arrived to exploit all the modern tools available by bringing information technology and agricultural science together for improved economic and environmentally sustainable crop production. In this context, Precision agriculture merges the new technologies borne of the information age with a mature agricultural industry. It is an integrated crop management system that attempts to match the kind and amount of inputs with the actual crop needs for small areas within a farm field. This goal is not new, but new technologies now available, allow the concept of precision agriculture to be realized in a practical production setting.

Keywords: Management, Precision agriculture, Soil system

INTRODUCTION

Agriculture production system is an outcome of a complex interaction of seed, soil, water and agro-chemicals (including fertilizers). Therefore, judicious management of all the inputs is very essential to be taken care by the growers. However, since long, it has been recognized that crops and soils are not uniform within a given field. To meet the forthcoming demand and challenge we have to divert towards new technologies, for revolutionizing our agricultural productivity through judicious management of all the inputs and it is the key point for the sustainability of such a complex system. Therefore, it is essential to develop eco-friendly technologies for maintaining crop productivity. This concern brings the scientific community to make precise application of all the inputs in a given land area rather increasing the land area which is already a permanent constraint. Precision management is the proper use of high-technology equipment and software to quantify field conditions and micromanaging the elements or resources at small or large land areas to obtain optimum benefits. It requires an understanding of time and space scales. Time scales are critical because operations occur when they will benefit the crop most. Space scales become a fundamental principle of field management because inputs and cultural practices are varied with soil type, pest population, or crop maturity. The challenge is to determine how to use time and space scales to advantage in developing an improved understanding of agricultural management. To fully achieve the goals of precision agriculture, management must be applied in a space and time context.

*Corresponding Author

The goals of precision management are actually quite clear. The first and foremost goal of the farmers is searching for higher yields and/or higher profits. Income provides the family needs, enhances the community, and keeps the farming operation viable. Reducing inputs normally results in lower input costs and lower impacts on air, land and water. Also, our society expects farmers to be natural resource managers and good stewards of the environment.

The goals of agriculturists-cum-natural resource manager should be:

A: Higher Yields and/or more profit
B: Reduced inputs and/or cost
And
A: To minimize environmental impacts
B: To preserve recreational enjoyment for future generations

Elements of Precision Agriculture: Precision farming basically depends on measurement and understanding of variability, the main components of precision farming system must address the variability. Precision farming technology is information based and decision focused, the components include, (the enabling technologies):

Global positioning system (GPS)
Remote sensing
Geographic information system (GIS)
Analysis/decision software
Variable rate technologies (VRT)
Electronics and instrumentation (yield monitors, soil sensors etc.)

Soil variability

Amongst the various catalysts, Soil is a spatial variable, initially to cover most of risks while growing. The vigorousness of any plants depends largely on its inner potential and on prevailing ambient conditions in soil for the plant to take a good start. Water-holding capacity or organic matter variation, along with topography, provides even a more interesting view of a field in which a producer places inputs or disturbs the soil. Other variables could be identified within this field to create a series of interacting elements. Among them topographic variation within fields can be collected from topographic maps, but the resolution on these maps is often insufficient to provide the necessary detail about variations within fields. For this, the detailed summary of soil sampling and interpolation techniques that potentially could be used to quantify soil variation. This technology defines these sampling methods as judgmental sampling, simple random sampling, stratified sampling, cluster sampling, nested or multistage sampling, systematic sampling, stratified systematic unaligned sampling, and search sampling. None of these methods are described herein, but all have been used to determine variability across a field.

The technology which affords the following objectives:

1. It allows for the application of fertilizers at variable rates according to variations in fertility levels.
2. It allows for the measurement of yield variability in fields.
3. It helps to increase yields by reducing variability.
4. It allows for soil sample sites to be accurately located within a field and fertility levels mapped.
5. It allows for the monitoring of yield as compared to soil test results.
6. It accurately pinpoints accurately location of significant soil variability.

Management of Soil Using Precision Agriculture Technology:

Soil is a major component of a sustainable agricultural system. Soil quality is the capacity of a soil to function in a productive and sustained manner, while maintaining or improving the resource base, environment, and plant, animal, and human health. The capability of a soil to function within ecosystem boundaries and interact with the environment, external to that system forms the basis for determining the potential impact of soil management systems on the environment. Thus, the measurement of soil quality should be a quantitative tool to help guide management decisions. Among the various measuring parameters, nutrient balancing of soil is one of the key approaches to presume a good input return. Thus, to make it possible, soil sampling assumes much greater significance when Precision or Site-specific Farming is adopted, because of the precision and representation required the variable rates of nutrient calculation and application, and the economics of the technology as a whole. Therefore, the following factors should be considered while sampling to estimate the nutrient status of soil:

Purpose

The purpose of soil sampling should be clearly determined prior to beginning a detailed sampling of the area. If one or more of the components of Precision Farming Technology is not available, a traditional sampling and testing approach will probably provide just as much useful data, thus saving the time and money spent on developing a detailed sampling strategy.

Resolution

The high resolution obtained through a high intensity of samples from a given area may not always translate into useful and practical information. The optimum number of samples required from a particular field is often determined from the historical logs and experience of high- and low-yielding areas, areas with identifiable features like depressions, etc.

Data Analyses

The data generated from the soil tests should be analyzed and interpreted with appropriate perspective that will reflect the site, cropping sequence, and resources available on the farm.

Soil Properties

Soil samples can be obtained to analyze for both physical and chemical properties. A baseline on soil physical properties, like textural analysis, bulk density, permeability, hardpans, and depth to clay, can be obtained through a onetime assessment. Unlike soil chemical tests it is not necessary to repeat a physical property test unless a soil amendment is added to ameliorate soil physical conditions like bulk density and hardpan. Field-scale alterations to physical properties like soil texture and depth to clay is not possible. Soil chemical properties include soil pH and extractable plant nutrient levels. Soil testing is recommended every season/year when Precision Technology is adopted for documenting improvements in soil pH and soil fertility levels.

Fertilizer recommendation

The key part of soil sampling and analyses is the fertilizer recommendation that accompanies each soil test report. This forms the basis for all the remaining activities involving inputs into the production cycle. Therefore, it is important to adhere to the rates of nutrients recommended. Altering the recommended rates on soil test reports for the sake of convenience will totally negate the benefits and may result in poor crop performance and economic losses.

Soil Sampling Techniques

Based on the shape and size of individual fields within a farm where crops are to be planted, suitable sampling schemes can be identified:

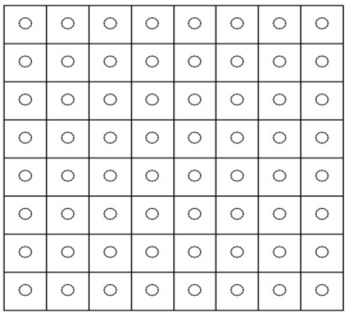

Fig. 1. Grid centred soil sampling.

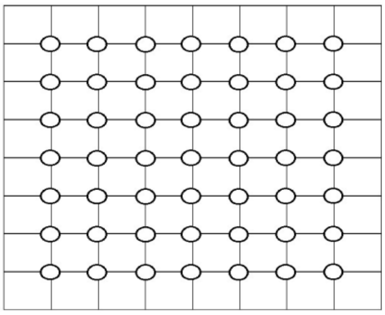

Fig. 2. Random sampling within grids.

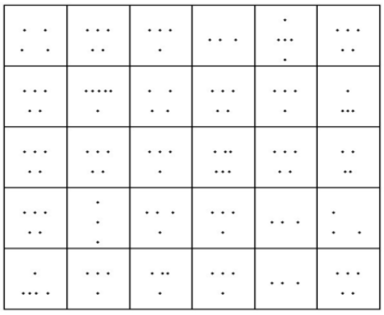

Fig. 3. Sampling at the grid intersections

Grid Sampling

A checkerboard-type grid can be created using special software such as SST Toolbox etc. The grid approach works best when large tracts of land are available. While these shapes and sizes can be adjusted to suit the need and convenience, the most popular grid sizes used are of 2-acre grids. Even one-acre grids are used on areas where a need for intensive sampling is identified. These fixed-area grids will therefore divide the field into equal square-shaped areas from within which samples will be collected. These square shaped areas are also referred to as 'cells'. There are at least three methods of sample collection within a grid that are practical. (1) One method is to go to the centre of the grid with the GPS unit and walk several steps away from the centre in all directions to collect samples from 3-5 spots randomly and consolidate them (Fig. 1).Being relatively simple, this grid-centred approach can be consistently done on any given field. However, for unbiased sampling, care should be taken to avoid concentration of samples around the centre point. (2) The second method is to collect samples at random from all across the grid without any bearing on the grid-centre (Fig 2) The sampling pattern will not be consistent across the cells but this approach will ensure a better randomization. This procedure may be more time consuming because various sampling points have to be individually accessed across the grid area. (3) The third method of grid sampling is to collect samples at grid line intersections (Fig 3). This approach will mathematically integrate the values (interpolate) between the points, which will enable creating contour maps based on the soil nutrient levels. The smaller the grid area, chosen, the higher the sampling intensity thus is increasing the costs.

Directed Sampling

A self-directed sampling is another scheme that is often adopted. This method requires a prior knowledge of the site characteristics that may be limiting the yield. Once these low/high yielding areas, soil types, areas under different cultural management, cropping systems, etc. are identified within a field, maps would be created to delineate the field accordingly and sampling would be conducted within these sub-regions. However, sampling based on factors that do not influence the yield should be avoided. This will effectively reduce the total number of samples.

In order to obtain optimum returns, a *Directed Sampling* scheme developed in conjunction with a good assessment of available resources and the ability to apply nutrients at variable rates is highly recommended. Assessment will be most useful by considering the maximum area or *Management Unit* across which a fertilizer rate cannot be varied. A Management Unit will be a subunit of the entire field under consideration and representative samples should be randomly collected and composited for analysis. The results will then be averaged across this area and applications will be made based on averages derived for this unit. Variations, if any, will be made among different units but not within any given unit. This process would be the most effective and economical of all.

Management of Collected Soil Data

As the soil samples have been collected as per latitude, longitude and altitude basis via. using grid or direct samplings, the samples can be processed to go under different nutritional analysis. The chemical analyses of the samples provide the nutritional inventory of the selected area. The prepared tabulated data can further be used to manage the field variability using variable rate technology (VRT).The VRT is the most advanced component of precision farming technologies, provides "on-the-fly" delivery of field inputs. There are two methods to use this VRT technology in management of nutrient unbalancing. The first method, in which, different maps are prepared using different thematic layers using Arc view 3.2a GIS software. This method includes the following steps: grid sampling of a field, performing laboratory analyses of the soil samples, generating a site-specific map of the properties and finally using this map to control a variable-rate applicator. During the sampling and application steps, a positioning system, usually DGPS (Differential Global Positioning System) is used to identify the current location in the field. The second method, Sensor-based, utilizes real-time sensors and feedback control to measure the desired properties on-the-go, usually soil properties or crop characteristics, and immediately use this signal to control the variable-rate applicator.

Sensor Technology in Soil

Intensive grid sampling is generally regarded as one of the most accurate methods of mapping the variability of crop and soil attributes in precision agriculture. However, intensive grid sampling is laborious, time consuming and expensive and thus impractical for implementation in large scale. It is, therefore, desirable to develop a more rapid means of obtaining spatial and temporal data for detailed variability mapping. The efficiency of site and time-specific crop-soil management and monitoring strategies can be improved by using low-cost sensors to estimate soil properties that impact crop yields. On-the-go soil sensor technologies that can serve as a rapid method for measuring soil mechanical, physical and chemical properties are steadily developing.

In present Scenario, various sensors have been developed to quantify the soil properties, required for accurate mapping within-field variability as per requirement. These sensor devices are fitted with a global positioning system (GPS) to allow for soil data to be captured on-the-go and instantaneously converted into distribution maps. This would facilitate real time monitoring and intervention of soil nutrient status, which can potentially offset limitations imposed by the inherent spatial and temporal variability in soil nutrient supply. Soil sensors can be used to generate real-time soil data, such as pH, electrical conductivity, salinity, dissolved oxygen and nutrient concentration, which are subsequently turned into geo-referenced maps to facilitate site-specific nutrient application. Numerous on-the-go sensors have been manufactured (Table 1) to measure mechanical, physical and chemical soil properties and most of them have been based on electrical and electromagnetic, optical and radiometric, mechanical, acoustic, pneumatic and electrochemical measurement concepts.

Table 1. The various types of soil sensor and their applications in the study of soil

Sensor type	Example applications	Reference
Electrochemical	Soil pH, Nitrate, Potassium	Adamchuk *et al.* (2007;2004)
Electrical and electromagnetic	Soil texture, Soil Moisture content, Soil depth variability (depth of topsoil, depth to hardpan), cation exchange capacity	Kim *et al*. (2009); King *et al*. (2005): Sudduth *et al*. (2003)
Optical and radiometric	Soil organic matter, Soil moisture	Rossel *et al*. (2006); Chang *et al*. (2001)
Acoustic	Soil texture, Soil bulk density, Soil depth variability	Grift *et al*. (2002)
Mechanical	Soil compaction, compacted soil layers	Stafford and Werner (2003); Manor and Clark (2001)

Generally, the main concerns in sensor performance efficiency are the issues of precision and accuracy. Precision refers to the ability of the sensor to repeat its own measurement in the same location and time, while accuracy refers to how well the sensor measurements correlate to an actual soil property that is determined using the conventional measurement technique.

Limitations of Precision Technology in Indian Context:

Although precision farming is proven technology in many advanced countries of the world but their scopes in India (also in other developing countries) are limited. Different scientists have reported certain constraints, which limited the scope for site-specific farming in India, are as given follows:

1. Small farms size and heterogeneity of cropping systems.
2. Lack of local technical expertise.
3. Infrastructure and institutional constraints including market uncertainty.
4. High initial investment.
5. Data availability and technical gaps
6. Complexity of tools and techniques requiring new skills.
7. Culture, attitude and perceptions of farmers including resistance to adoption of new techniques and lack of awareness of agro-environmental problems.
8. Uncertainty about the returns from investments on new equipment.

CONCLUSION

Precision agriculture in today's agriculture is being proven as a pavement in enhancing agricultural productivity without jeopardizing the ecological balance. This technology gives farmers the ability to use crop inputs more effectively including fertilizer, pesticides, tillage and irrigation water. More effective use of inputs means greater crop yield and/or quality, without polluting the environment. This technology also cuts an extravagant investment on required inputs which is a prime importance of a farmer to look upon. But, the technology is mainly prevalent in the developed countries. India is still to take revolutionary step in precision agriculture but the basic issues which hurdles this technology to flourish in Indian context are: fragmented land holdings, heterogeneity of crops and livestock and concept of farm families in the rural conditions etc.

The on-the-go sensors have the advantage of providing non-destructive and rapid quantification of soil variability to enable precision soil nutrient management and monitoring. However, the reliability of the data taken about crop-soil properties by the on-the-go sensor under different growing condition is still unclear. But, the increasing population in association to climate change requires a commensurate increase in agricultural productivity. Key to this challenging task is to ensure sustainable soil productivity while maintaining high crop yields and reducing environment pollution. Thus, to recover from all these factors, a sensor technology for nutrient management is a good way to achieve such goals.

REFERENCES

Adamchuk, V.I., Lund, E.D., Reed, T.M. and Ferguson, R.B. (2007). Evaluation of an on-the-go technology for soil pH mapping. Prec. Agric., 8: 139-149.

Adamchuk, V.I., Hummel, J.W., Morgan, M.T. and Upadhyaya, S.K. (2004). On-the-go soil sensors for precision agriculture. Comp. Electr. Agric., 44: 71- 91.

Atreya, K., Sharma, S., Bajracharya, R.M. and Rajbhandaric, N.P. (2008). Developing a sustainable agro-system for central Nepal using reduced tillage and straw mulching. J. Environ. Manag., 88: 547- 555.

Bah, A., Balasundram, S.K. and Husni, M.H.A. (2012). Sensor technologies for precision soil nutrient management and monitoring. American Journal of Agricultural and Biological Sciences 7 (1): 43-49.

Balasundram, S.K., Mulla, D.J. and Robert, P.C. (2007). Spatial data calibration for site-specific phosphorus management. Int. J. Agric. Res., 2: 888-899.

Balasundram, S.K., Husni, M.H.A. and Ahmed, O.H. (2008a). Spatial variability of pineapple yields on a tropical peat. Crop Manag. (Online). DOI: 10.1094/CM-2008-0418-01-RS

Balasundram, S.K., Husni, M.H.A. and Ahmed, O.H. (2008b). Application of geostatistical tools to quantify spatial variability of selected soil chemical properties from a cultivated tropical peat. J. Agronomy, 7: 82-87.

Barton, A.P., Fullen, M.A., Mitchell, D.J., Hockinga, T.J. and Liub, L. (2004). Effects of soil conservation measures on erosion rates and crop productivity on subtropical Ultisols in Yunnan province, China. Agric. Ecosyst. Environ., 104: 343-357.

Brevik, E.C., Fenton, T.E. and Lazari, A. (2006). Soil electrical conductivity as a function of soil water content and implications for soil mapping. Prec. Agric., 7: 393-404.

Chang, C.W., Laird, D.A., Mausbach, M.J. and Jr., C.R.H. (2001). Near-Infrared Reflectance Spectroscopy– Principal Components Regression Analyses of Soil Properties. Soil Sci. Soc. Am. J., 65: 480-490. Grift, T.E., M.Z. Tekeste and R.L. Raper, 2002. Acoustic compaction layer detection. Tran. ASAE, 48: 1-8.

Hatfield, Jerry, L. (2000). Precision Agriculture and Environmental Quality: Challenges for Research and Education. a national workshop, “Precision Agriculture and the Environment: Research Priorities of the Nation,” held in cooperation with the USDA’s Natural Resources Conservation Service and Agricultural Research Service.

Kim, H.J., Sudduth, K.A. and Hummel, J.W. (2009). Soil macronutrient sensing for precision agriculture. J. Environ. Monit., 11: 1810-1824. King, J.A,, P.M.R. Dampney, R.M. Lark, H.C. Wheeler and R.I. Bradley *et al*., 2005. Mapping Potential Crop Management Zones within Fields: Use of Yield-map Series and Patterns of Soil Physical Properties Identified by Electromagnetic Induction Sensing. Prec. Agric., 6: 167-181.

King, J.A,, Dampney, P.M.R., Lark, R.M., Wheeler, H.C. and Bradley, R.I. *et al.* (2005). Mapping Potential Crop Management Zones within Fields: Use of Yield-map Series and Patterns of Soil Physical Properties Identified by Electromagnetic Induction Sensing. Prec. Agric., 6: 167-181.

Larson, W.E. and Pierce, F.J. (1991). Conservation and the enhancement of soil quality. P. 175203. In Evaluation for aSustainable Land Management h. Pap. Int in the Developing World. Vol. 2. Tec Board for Soil Res. and Management.Bangkok. Thailand.

Larson, W.E., Lamb, J.A., Khakural, B.R., Ferguson, R.B. and Rehm, G. W. (1997). Potential of site-specific management for nonpoint environmental protection. The Site-Specific Management for Agricultural Systems, F.J. Pierce and W.W. Frye, ed. American Society of Agronomy, Crop Science Society of America, and Soil Science Society of America, Madison, WI.

Manor, G. and Clark, R.L. (2001). Development of an Instrumented Subsoiler to Map Soil Hard-Pans and Real-Time Control of Subsoiler Depth. 1st Edn., ASAE, USA., pp: 12.

McCormick, S., Jordan, C. and Bailey, J.S. (2009). Within and between-field spatial variation in soil phosphorus in permanent grassland. Prec. Agric., 10: 262-276.

Mortensen, D.A., Johnson, G.A., Wyse, D.Y. and Martin, A.R. (1994). Managing spatial variable weed populations. In Site-Specific Management for Agricultural Systems. P.C. RoLert, R.H. Rust, and W.E. Larson (eds.). 2nd Intern. Conf. On site-specific Management *for* Agricultural Systems. 2i7-30 March, Minneapolis, MN.

National Research Council (1993). Soil and water quality: an agenda for agriculture. National Academy Press, Washington. D.C.

PPI (1999). Site-Specific Management Guidelines. 1st Edn., Potash and Phosphate Institute, Atlanta.

Rao, S., Mylavarapu and Wonsuk Daniel Lee (2002). Afact sheet of the Soil and Water Science Department, UF/IFAS Extension. Published February 2002. http://edis.ifas.ufl.edu.

Rossel, R.A.V., Walvoort, D.J.J., McBratney, A.B., Janik, L.J. and Skjemstad, J.O. (2006). Visible, near infrared, mid infrared or combined diffuse reflectance spectroscopy for simultaneous assessment of various soil properties. Geoderma, 131: 59-75.

Schirrmann, M. and Domsch, H. (2011). Sampling procedure simulating on-the-go sensing for soil nutrients. J. Plant Nutr. Soil Sci., 174: 333-343.

Srinivasan, A. (2006). Handbook of Precision Agriculture: Principles and Applications. 1st Edn., Routledge, New York, ISBN: 1560229543, pp: 683.

Stafford, J. and Werner, A. (2003). Precision Agriculture. 1st Edn., Wageningen Academic Publishers, Wageningen, ISBN-10: 9076998213, pp: 783.

Sudduth, K.A., Kitchen, N.R., Bollero, G.A., Bullock, D.G. and Wiebold, W.J. (2003). Comparison of electromagnetic induction and direct sensing of soil electrical conductivity. Agron. J., 95: 472-482.

Sun, B., Zhou, S.L. and Zhao, Q.G. (2003). Evaluation of spatial and temporal changes of soil quality based on geostatistical analysis in the hill region of subtropical China. Geoderma, 115: 85-99.

Van De Grift, T., Wolfman, S. A., Yasuhara, K. and Anderson, R. J. (2002). "Promoting interaction in large classes with a computer-mediated feedback system," *Washington State University*, pp. 1-10.

Wagenet, R.J., and Hutson, J.L. (1992). LEACHM: Leaching estimation and chemistry model. A process-based model of solute movement, transformations, plant uptake, and chemical reactions in the unsaturated zone. Version 3. Dep. Of Soil, Crop, and Atmosperic Sciences, Res. Series No. 92-3. Cornell University, Ithaca, NY.

Wollenhaupt, N.C., Mulla, D.J. and Gotway Crawford, C. A. (1997). Soil sampling and interpolation techniques for mapping spatial variability of soil properties. In Pierce, F.J., and E.J. Sadler (eds.) the State of Site-Specific Management for Agriculture. American Society of Agronomy, Crop Science Society of America, and Soil Science Society of America, Madison, WI. Pp. 19-53.