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Site Specific Land Management

General Concepts and Applications

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1 GENERAL BACKGROUND

Cultivation of crops certainly dates back to the earliest age of humankinds. People have been growing and managing crops since the very beginning and more importantly the crop management concept has been found to be developing with the civilization. Although most of the efforts of the ancient people were mainly focusing on collecting foods for their living, the knowledge and experience in crop and land management increased and new farming techniques evolved with time. Shifting cultivation, rotational cropping, irrigating, manuring and ashing their fields etc. can be a few examples of such activities. As the time goes, people got more and more familiar with crops, their growing habits and many other land management practices which were beneficial for yield increment. Identification of crop specific soil and climate requirements, fertilizer and manuring responses of the crops, knowledge on the occurrence of pest and disease and their control measurers helped the farmers to plan and manage their field and other agriculture operations in an efficient way for higher income.

Manual cropping was the main way of cropping system in the past because they didn't have other choices. The benefit with this method was a considerable opportunity for the farmer to directly observe the condition and progress of each part of their field and help manage them accordingly. Since the evolution of commercialization in agriculture, as can be seen through the increased farm holdings or larger parcels, intensive crop cultivation, mechanization and automation in agriculture etc. individual and manual treatment of each parts of land in a large scale became more and more difficult or rather impossible. On the other hand, the cost involved increased so high that the farm income keeps on always lagging behind. With the enlargement of fields and intensive farming practices, it has become more difficult to take account of their local field variability manually without a revolutionary development in technologies (Stafford, 2000). Consequently, the farmers started treating their whole field as a single management unit for inputs applications and management and local variability did not get much attention. This uniform application of farm inputs caused reduced input use efficiency as inputs were applied in some parts of the field. The reduced input use efficiency eventually ended up with the waste of inputs accompanied with economical losses as well as more importantly unfavorable environmental impacts (Mulla and Schepers, 1997). As people started thinking of the financial, environmental and social cost, this uniform input application became a primary factor and recently received a serious concern. This led to the invention of a new crop and land management idea which would advocate the judicious utilization of input resources to the field and could be economically, and environmentally friendly.

2 INTRODUCTION

In general, increasing farm input use efficiency hence the increment in yield requires a new farming concept that focuses on fine-tuning of production inputs like seed, nutrient, water, pesticide, and energy and labor for smaller management units. This concern is encompassed in the philosophy of precision agriculture which is also known as precision farming system, site-specific crop management (SSCM) or site-specific land management (SSLM). Conceptually, SSLM is the way of managing crop land in its local environment taking into account the existing field variable pattern. It can also be referred that managing local variability is the key point in SSLM plans. McBratney and Whelan in 1995 concluded that the increasing awareness of large variability between and within production fields also contributed for the inception of this faring concept. However, the premises underlying site-specific management, namely that heterogeneity particularly that of soil influences the productive potential of agriculture land, is not a new concept. In more specific way, site-specific crop management can be defined as the management of production inputs such as fertilizer, limestone, seeds, herbicides, insecticides in the soil environment on a within-field basis such that it would facilitate to reduce waste, increase profits still maintaining the quality of the environment. This is the information and technology based agricultural management system to identify, analyze and manage site-soil spatial and temporal variability within fields for optimum profitability, sustainability and protection of the environment. SSLM seems to be one of the prospective leading technologies in crop production in a new century.

This type of land management concept is different from the age-old conventional farming system in the sense that it always considers and treats the local field variability with increased input use efficiency which could affect the overall production potential and also keeps respecting to the creation of eco-friendly environment. The difference can be made clear from the following Figure 1. This explains how SSLM differs from the conventional approach of cropping. This also highlights its potential for soil quality based management for sustainable land use (Tóth et al, 2007). In the Conventional approach all fields planted with the same crop (rice-R or wheat-W) are managed similarly and management applications from leveling to the insecticide applications in this case do not vary much between and within fields. This type of input treatment can also be termed as "blanket treatment". However, in the SSLM approach, each field planted with the same crop may be treated specifically; termed as differential treatment (e.g., R1 is different from R6) in the specific management zones.

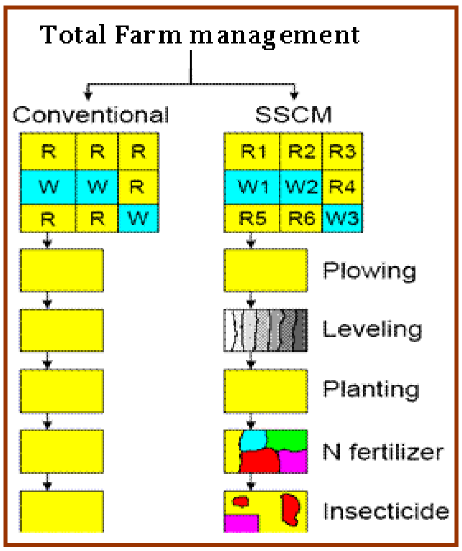

Figure 1 Site-specific land management operations Vs. Conventional farm management (Dobermann and Bell, 1997)

SSLM also conceptualizes for the sustainable utilization of agricultural resources leading to the economic benefits. This concept can be proved with a help of the following figure 2. This shows clearly how it provides the indirect economic benefits through targeting the resources to the identified more responsive areas within a field without necessarily increasing resources used. The field area is characterized as Response-1 and Response-2. Response-1 is the yield from that part of the field area which shows lesser productivity compared to the more productive area which gives response-2 within the given parcel. During the input applications, Response-2 might be underexploited when the mean field treatment is taken as the optimal economic application for Response-1. When recourses (ΔA) from the Response-1 are transferred to the areas of Response-2, the yield gain (ΔY2) from this part is greater than the yield reduction (ΔY1) in the areas of Response-1.

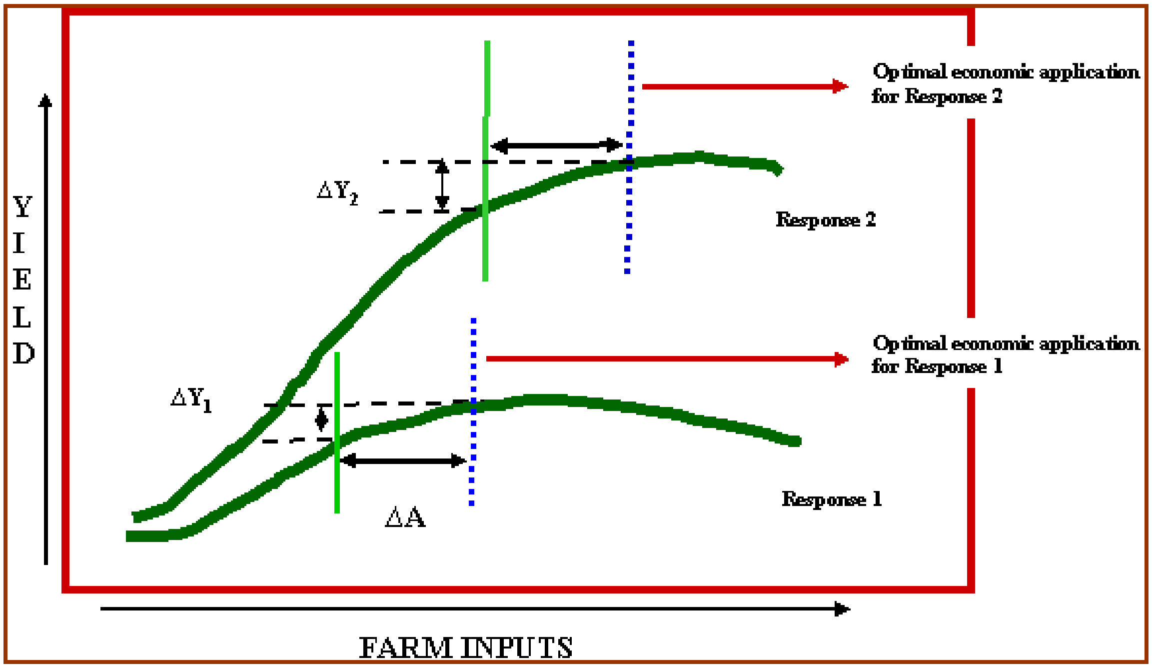

Figure 2 Generalized production impetus for Site-specific management (After Whelan, 2003)

Definition: Shibusawa (1998) conceptualized site-specific land management as a system approach to re-organize the total system of agriculture towards a low-input, high efficiency, sustainable agriculture.

More specifically it can be referred to as an aspect of precision agriculture that relates to the differential management of a crop production system in an attempt to maximize production efficiency and quality and attempts to minimize the environmental impact and risk. This is an optimization of input use and the environmental qualities such that yield get maximized without jeopardizing the environment. It operates by matching resource application and agronomic practices with soil attributes and crop requirements as they vary across a field and also by crops (Tóth et al. 2005). Collectively these actions are referred to as the 'differential' treatment of field variation as opposed to the 'uniform' treatment that underlies traditional management systems.

This new farming approach mainly benefits from the emergence and convergence of several technologies, including the global positioning system (GPS), geographic information system (GIS), miniaturized computer components, automatic control, remote sensing, mobile computing, advanced information processing and telecommunications (Gibbons, 2000). Agriculture industry is now capable of gathering more comprehensive data on production variability in both space and time. The desire to respond to such variability on a fine scale has become the goal of SSLM (Whelan et al., 1997).

Miller et al. (1999) listed three criteria that must be satisfied in order for SSLM to be justified. These are (1) that, significant within-field spatial variability exists in factors that influence crop yield, (2) that, causes of this variability can be identified and measured and (3) that, the information from these measurements can be used to modify crop management practices to increase profit or to decrease environmental impacts.

3 OBJECTIVES OF SSLM

The objectives of site-specific farming are similar to using integrated pest management, sustainable agricultural practices, soil conservation measures, and/or the use of best management practices. The objectives can be made possible with the use of recently developed technologies in farming system and in agriculture engineering. The major objectives of the SSLM are to:-

- Increase production efficiency and profits;
- Improve product quality;
- Use the chemicals efficiently and judiciously;
- Conserve the energy; and
- Protect soil and ground water

4 BENEFITS OF SSLM

The benefits of SSLM can be of multifold as directly from the economic benefit through the increased yield or income and indirectly from the environmental and social benefits. This can be made possible through the increased input use efficiency or decreased waste of inputs and managing the field parcels according to their production potential. Minimized and judicious use of chemicals or pesticides, application of low energy consumption theory and sustainability in the whole production system are other indirect benefits leading to the ecologically and environmentally better society.

The impact of SSLM technologies in agriculture production is expected in two areas: profitability for the producers and ecological and environmental benefits to the public.

4.1 Profitability

SSLM allows precise tracking and tuning of farm production for achieving higher profits. SSLM technologies provide farmers with opportunities of changing the distribution and timing of fertilizers and other agrochemicals based on spatial and temporal variability in a field. Use of variable rate technology helps in minimizing the loss and reduces the risks. By knowing the cost of inputs, farmers can also calculate the cash return over the costs for each hectare. Certain parts within a field, which always produce below the breakeven line, can be isolated for the development of a site-specific management plan (Goddard, 1997). In studies under conditions in Germany, the benefits of site-specific Nitrogen- fertilizing were found to be 25 and 50 Euro per hectare (Schmerler, 1997). Muller (2003) indicated that higher benefits are expected if site-specific technology is applied on high value crops.

4.2 Environment

Strict environmental legislations have been put into action in all of the developed countries and even some in developing countries. SSLM provides the means of precise and targeted application, recording of all field treatments at the meter scale, tracking from operation to operation, and transfer of recorded information with the harvested products all of which assist in enforcement of the legislations (Stafford, 2000). A study conducted in two adjacent coarse textured potato fields, one treated with uniform rate technology for nitrogen fertilizer and the other with variable rate technology, has demonstrated the positive effect of VRT in reducing the ground water contamination by nitrate leaching (Whitley et al., 2000). With the availability of topographic data for fields implemented with SSLM technologies, the interaction between tillage and soil/water erosion can be examined and thus, reduction in erosion can be achieved (Schumacher et al., 2000). English et al. (1999) found the profitability and environmental benefits of site-specific application of N using EPIC (Erosion Productivity Impact Calculator) crop growth simulation model.

This technology driven farming system has been a part of a daily agriculture in the developed countries where agriculture has already been mechanized and automated and farmers are all aware of the production function and enthusiastic to the adoption of new farming technologies. But the dissemination of this technology to developing countries is very slow and still to be improved. However, due to the overall benefits, site-specific management has attracted the interest and seen some limited adoption in Asian countries. Reasons for this interest include:

- Global demand for environmentally safe agriculture;
- Pressure to strengthen the value of agricultural products to survive in competitive global markets; and
- Labor shortage due to a decreasing and aging rural population (Shrinivasan, 1999).

Social concern regarding environmental problems such as ecosystem damage and ground water pollution by heavy use of agricultural chemicals that was seen as necessary to increase yields to feed rapidly increasing population on a limited amount of arable land;

However, Wang (2001) has seen a greatly reduced time lag in the adoption of new technologies in developing countries due to the advancement in the technology and entering the whole system into the information based economy era.

5 IMPORTANT ATTRIBUTES TO BE CONSIDERED FOR SSLM PLANNING

The planning and application of SSLM in any area should start considering different attributes that might influence the whole crop management system. Among the variety of factors concerned, soil is the most important attribute and hence should receive a major concern. Several researches on SSLM have demonstrated that many soil attributes have high spatial variability. Assessment of this variability and its efficiency play a significant role in planning SSLM but one should be careful to its applicability and feasibility. Because sometimes this variability is beyond that which can be economically assessed using soil sampling, laboratory analysis and spatial interpolation (McBratney and Pringle, 1997).

In a broader scale, the variation in crop yield can be considered as the consequence of variability in the interaction between crop genetics and the exposed environment. However at the field scale, site-specific variation in soil type, texture, soil structure integrity, soil moisture content and its availability and soil nutrient chemistry will significantly contribute to the spatial variability in crop yield. The most important process that brings about the variation in soil attributes in any landscape include the soil forming process i.e. soil genesis which defines the type of soil developed and governs majority of the properties e.g. texture, horizon color, cation exchange capacity (CEC), mineralogy and soil depth. Moreover, soil management practices and cropping system significantly influence within-field soil variability. These may impact more dynamic soil properties like nutrient balance, moisture regimes, structural stability, air circulation and drainage. Similarly, factors like erosion and sedimentation can also influence the field variability in some extent. The variation is also found to be a scale dependent. Generally, the overall variation may increase as the area of study increases. Whelan (2003) categorizes this overall variability in soil attributes as:-

- Soil textural and structural variability;
- Variability in soil organic matter;
- Soil moisture variability;
- Variability in soil nutrient content and their availability; and
- Variability in soil pH;

5.1 Soil textural and structural variability

Variation in soil texture and structure are very common phenomena which directly influence the yield potential of any site. Textural variability may contribute to the variation in nutrient storage and availability, water retention, availability and transport, binding and stability of soil aggregates etc. This may be influenced by nature and properties of parent material, type of land management practices and other processes like erosion and sedimentation. It can be expected that alluvial soils are likely to be more variable, soil properties of the plough layer may show less variability than the lower horizons through mixing by tillage operations. The structure in a cropped land may be different from soils of rangeland or pastures. Compacted soils have degraded structure while pulverized soils may show good structure. Soil structure governs the biological activity, physical penetration, growth and anchorage of roots, air and water movement, porosity etc.

5.2 Variability in Soil Organic Matter

Soil organic matter (SOM) has positive influence on both physical and chemical fertility of soils. It plays a significant role in maintaining soil physical properties, storing and releasing moisture and plant nutrients and influencing the quantity and quality of soil microbial activity. Soil temperature, precipitation, land management, vegetation and other bio-inputs, biological activity etc. may influence the formation or oxidation of SOM and hence creates SOM variation in a site. The more the SOM content and its variability in an area, the more one could expect biological diversity which ultimately aids to the soil variability due to the physical activities of the animals and sometimes chemical reactions due to the microbes.

5.3 Soil moisture variability

Variation in soil moisture content and its movement in soil are governed by many factors like soil texture, structure, soil depth, depth of water table, topography, SOM content, irrigation and precipitation, temperature and other climatic parameters. Soil moisture content and its form of availability are crucial for the growth and development of plants. It influences the dissolution, absorption and transportation of plant nutrients, soil biological activity, soil temperature variation and oxidation and reduction state of soil matrix. This variability in soil system depends on the volume and distribution of water in soil because this variability may decrease with the increase in soil moisture content. Drainage and water management practices influence the soil moisture variability and can also be related with yield variability. Drainage probably causes more variability in the yield of certain crops than any other factors. Erosion and sedimentation still can influence yield significantly.

5.4 Variability in soil nutrient content and their availability

The fundamental basis of yield increment is the supply and availability of primary, secondary and trace elements to the growing plants. Texture, structure, moisture, mineralogy, soil pH, SOM, application of fertilizers, management techniques influence the variability of soil nutrient status in any site which is again explained by CEC of the soils concerned. Acidic soils for instance have more aluminum content but their concentration becomes so high that it could be toxic to the plants. Some soils could be measured as high phosphorus content still has very less availability because of their fixation. This variability may not only differ between the farms but also vary even across a paddock or cropped row. The yield dynamics can be directly linked with the variability of nutrients and their status of presence.

5.5 Variability in soil pH

Soil pH is an important property of soils determining the availability and toxicity of nutrients elements to the plants. Very high and very low soil pH is not good for the growth and development of plants. This is influenced by climate and precipitation, parent material, management techniques that show the spatial and temporal variations in soil reactions. Variation in pH across fields will undoubtedly affect the availability of nutrients if applied as fertilizer in uniform quantities. Intermediate pH around 6-7.5 in the pH scale can be considered as good for most of the crop production.

Moreover, different soil management practices also play a crucial role in the overall variability of the above mentioned soil attributes. Rotational cropping, fallowing, shifting cultivation, intensity of cropping i.e. intensive or conventional system etc. are the few such examples.

6 BASIC COMPONENTS OF SSLM

SSLM basically depends on measuring, understanding and managing the existing field variability. Therefore the main components of this system must address the existing within-field variability and its proper and efficient management. According to Whelan (2003), there are 5 basic components for SSLM (Figure 3):

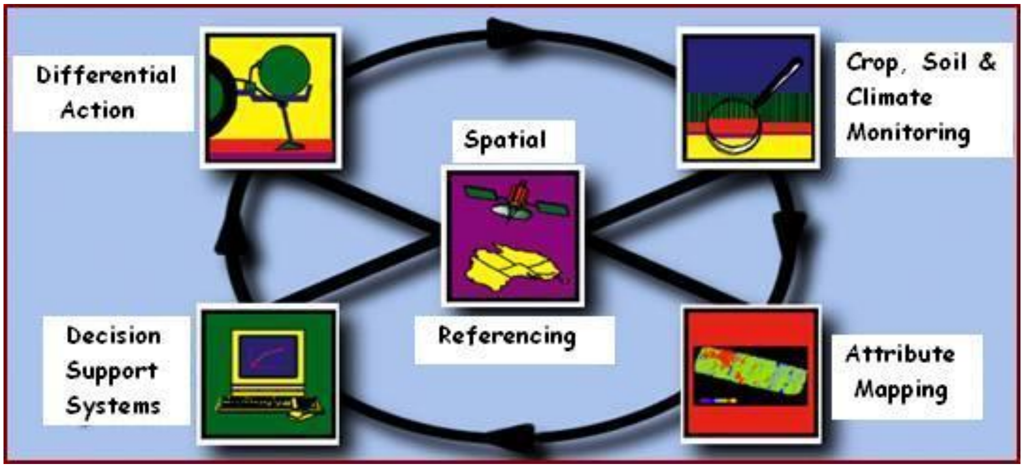

Figure 3 Components of a Site-specific land management

6.1 Spatial or Geo-Referencing

For all facets of field operation in SSLM, more accurate information on the ground position is a must. Since SSLM is a location specific management, the precise supervision of each part of the field might be needed to apply the site specific treatment in that part which could be totally different to its closest neighborhood. So we must know the exact locations of each part of the field and geo-referencing is the only way to deal with. Data collected on the spatial variation in soil and crop attributes must be linked with their corresponding geographical position in the field and of the technologies available, Global Positioning System (GPS), a satellite-based navigation system, is most widely used for this task at present.

6.2 Crop, Soil and Climate Monitoring

Soil and crop attributes must be monitored at a finer scale possible to implement any site-specific management plan. When observations are geo-referenced they can be used to understand the spatial variability of the attributes within-field. Different yield monitoring sensors have been developed to identify crop yield variability across the field. Similarly, different soil attributes can also be monitored on-the-go by commercially available sensing instruments such as electromagnetic sensor, nitrogen sensor, soil moisture content sensor, soil temperature sensors etc. The selection of these sensors depends on the degree of accuracy needed, efficiency, affordability and availability of the sensors.

6.3 Attribute Mapping

With the data from the sampled areas, the values for soil and crop attributes must be predicted for unsampled locations across a field with the maximum reduction of errors. This enables detailed representation of the spatial variability within an entire field through the creation of continuous and smoothed map. Different pedometrics and Geographic Information System (GIS) tools have been used to produce accurate maps based on the type and amount of data to be used.

6.4 Decision Support Systems

Based on the degree of variability within-field, the necessity of unique treatment can be accessed. Knowledge about the effects of field variability on crop growth and the suitable agronomic responses can then be combined to formulate differential treatment strategies. Computers and different software provide a great help in this regard.

6.5 Differential Action

With the devised treatment strategies that best deals the spatial variability, different agronomical operations such as sowing, irrigation, fertilization, liming and pesticide application, tillage etc can be varied in real-time across a paddock. Variation in treatment corresponds to the mapped variation in the field attributes measured and is made by different variable rate applicators.

7 THE PROCESS OF SSLM

The SSLM practice can be put into action considering the above mentioned basic components. Since these components act in a cyclic way, they can be practically implemented with the following steps.

7.1 Assessing variation

Assessing variability is the critical first and the major step in SSLM. Factors and the processes that regulate or control the crop performance in terms of yield vary in space and time. The acquisition of variation in soil and yield information can be made possible effectively and efficiently with recently developed techniques over traditional methods.

The methods employed for gathering information about soils and yields will be discussed here under.

7.1.1 Monitoring soil spatial variability

7.1.1.1 Discrete Soil sampling

Sampling and analyzing the soil samples from the fields are the basis for the site-specific crop management. This allows knowing the variability of soil attributes within the field. The conventional soil map scales are too coarse resulting in large amounts of spatial variability of soil attributes within a mapping unit. Therefore the soil attribute data in conventional soil maps are rarely useful to identify within-field spatial variability of yield determining factors (Mausbach et al., 1993).

Traditional discrete sampling procedures are either grid based or statistically based at random. In discrete point sampling, grid center method, or grid cell method, can be used for sampling the whole field based on the cells of known dimensions. Grid distance of 30-50 meter is required in order to accurately determine the spatial variation of soil properties and to produce geo-representative agro-resource maps usable for SSLM (McBratney and Pringle, 1997; McBratney and Whelan, 1999; Haneklaus et al., 1997). However, resent results in Europe has suggested the distance of 10 meter suitable for SSLM applications. Schnug et al. (1998) suggested that geo-referenced grid soil sampling is however, not appropriate at farm level as it is not cost effective. Approaches for a reduction of sampling efforts which warrant a high accuracy of estimates include variance quad-tree (VQT) method (McBratney et al., 1999), directed sampling (Mulla, 1997; Hanaklaus et al., 2000; Basso et al., 2001), self surveying (Haneklaus et al., 1998) etc.

Directed sampling method is an improvement of grid sampling which uses prior information to guide the determination of sampling points. Based on the previous knowledge of soil variability, the sampling locations can be chosen to make them truly representative. This designated set of sample points is referred to as targeted or directed sampling scheme (Lund et al., 1999). It has potential to reduce the number of soil samples required compared with intensive grid sampling. Francis and Schepers (1997) used selective soil sampling based on color, texture, depth, slope and erosion characteristics to produce fertilizer recommendation.

7.1.1.2 On-the-go soil sensing

This refers to the practice of measuring the soil variables on-the-go. Sensors that measure a variety of essential soil properties on-the-go are being developed. It can provide soil data without the need to collect and analyze samples and can be linked to GPS and computer for on-the-go spatial data collection (Kitchen et al., 2003). Collecting data on the soil variables during a pass over the field enhances the observation resolution with minimum cost. Different kinds of soil sensors has been developed for sensing soil attributes like soil moisture, soil nitrogen and apparent electrical conductivity, carbonate rates, soil porosity. These sensors work with different technologies like electro-magnetic induction, electric conductivity, and ion selective field effect transistors. The most common form of on-the-go sensor used for precision agriculture is the apparent electrical conductivity sensor using electromagnetic induction (EMI) or rolling electrodes (Jaynes et al., 1995). The following paragraph describes in more detail about this commonly used sensor and its working principle.

Apparent electrical conductivity of the soil profile is a sensor-based measurement that can provide an indirect indication of important soil physical and chemical properties. To distinguish the electrical conductivity (EC) measured by the sensors from the soil science definition of EC (based upon conductance of a saturated soil paste extract), we will call the sensor measured EC as apparent EC (ECa). Soil salinity, clay content, CEC, clay mineralogy, soil pore size and distribution, and soil moisture content are some of the factors that affect ECa (McNieill, 1992; Rhoades et al., 1999). The ECa mapping was firstly employed for locating saline seeps in the northern Great Plains (Halvorson and Rhoades, 1974).

According to Rhoades et al., 1999, three pathways of current flow inside the soil system contribute to the ECa and these three pathways as shown in the following figure 4 are:

- Soil liquid phase, via salts contained in soil water occupying large pores;
- Moist soils via the exchangeable cations associated with clay minerals; and
- Solid phase through soil particles in directed and continuous contact with one another.

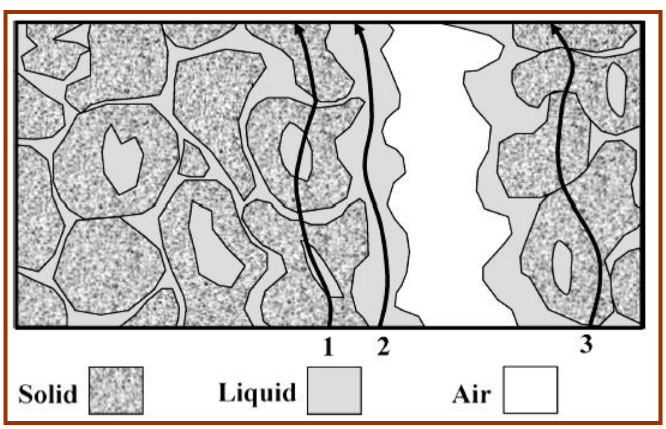

Figure 4 Pathways of current flow in the soil system

Because of these three pathways of conductance, the ECa measurement is influenced by several soils physical and chemical properties like soil salinity, saturation percentage, water content, and bulk density. Another factor influencing ECa is temperature so it needs calibration of the equipment before measuring ECa of any site.

Most of the variation in ECa can be related to salt concentration in saline soils (Williams and Baker 1982). In non-saline soils, conductivity variations are primarily a function of moisture content, soil texture, and CEC (Rhoades et al., 1976). Other yield determining soil attributes also inferred by ECa include soil moisture content (Sheets and Hendrickx, 1995), CEC and exchangeable Ca and Mg (McBride et al., 1990), depth to clay pans (Kitchen et al., 1999) and SOM (Jaynes, 1996). Because many of these factors impact on plant growth, ECa has become one of the most reliable and frequently used indirect measurement to characterize within-field variability of yield determining soil factors for implementing SSLM plan (Rhoades et al., 1999). Two types of within-field ECa sensors are commercially available for agriculture purpose;

- Electrode-based sensor requiring soil contact, and;
- Non-contact electromagnetic induction (EMI) sensor

In the electrode based system, sensors are pulled or rolled across the fields making direct soil contact and measurements are recorded simultaneously. A commercial device implementing the electrode-based approach is the Veris 3100 (figure 5), which uses six rolling coulters for electrodes and provides two simultaneous ECa measurements (Lund et al., 1999).

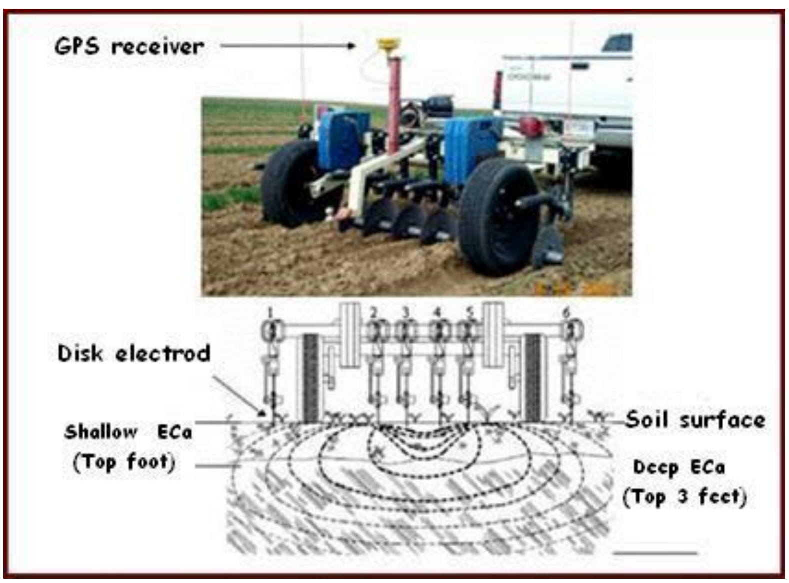

Figure 5 Veris 3100 EC Mapping System (top) and a diagram of the Veris EC Unit showing the disk-electrodes and electrical network (Source: After Farahani et al, 2007)

The rolling disks record soil EC readings from two different depths every second. One pair of disk-electrodes induces current into the soil and the change in voltage is measured across the other two pairs of disk-electrodes resulting in simultaneous EC measurements for the top 1 foot of soil and the top 3 feet of soil. A Global Positioning System (GPS) receiver mounted on the Veris unit records the location of each soil ECa measurement point in the field. A field is usually mapped by driving the entire field on parallel paths from 40 to 60 feet apart. With speeds between 8 and 15 mph, the Veris records 50 to 100 soil ECa readings per acre.

The non-contact sensors as their name says do not make a direct soil contact for field ECa measurements. This EM-based ECa sensor most often used in agriculture is the EM38 (Geonics, Limited, Mississauga, Ontario, Canada), which was initially developed for root-zone salinity assessment (Rhoades and Corwin, 1981). The EM38 induces eddy current loops into the soil with one coil and determines conductivity by measuring the resulting secondary current induced using another coil. Both sensors have been demonstrated to give similar results (Sudduth et al., 1999). The latest model as in figure 6 is dual-dipole EM38 unit (EM38DD).

The mobile EM equipment consisted of EM38DD sensor housed in a polyvinyl sled, GPS receiver and a field computer attached to EM38DD and four wheels drive all terrain vehicles to drag the sled.

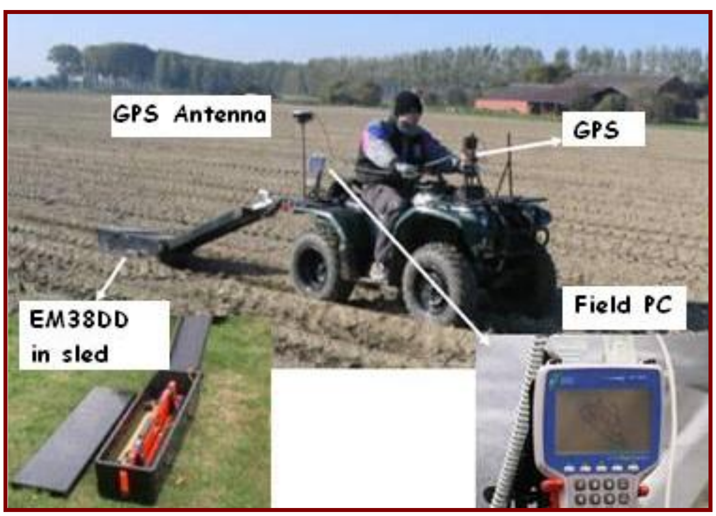

Figure 6 Mobile EM38DD sensor system with the accessories (Adhikari K., 2006)

The EM38DD measures simultaneously the ECa in two orientations i.e. ECa-vertical and ECa-horizontal and each orientation has a different depth response profile. McNeill, 1992 stated that Geonics EM38 with its vertical and horizontal dipole can measure soil variability in the depths of approximately 1.5m and 0.75 m, respectively. Therefore, the horizontal dipole has a major influence of the topsoil, while the vertical orientation has a dominant influence of the subsoil. The ratio of the two orientations gives an indication about the heterogeneity of the soil profile, which is important in agricultural practices. The geometric mean of apparent electrical conductivity (ECa-GM) calculated as, ECa-GM = (ECa-Ver. * ECa-Hori.)½ has been often used as secondary soil information (Crowin et al., 1999). This sensor records the location and ECa data every 2 seconds interval corresponding to measurement distance of 2 meters along the measurement transects of 5 meters apart.

7.1.2 Generation of Soil ECa map and its importance in SSLM

The data logger or field PC of the above equipments connected to the sensors records the soil ECa and GPS data which can be downloaded for further processing. Since the sensors collect data in one to few second intervals, the ECa file is usually large and therefore it can be best presented graphically as an ECa map. The graphical representation of soil ECa data points (figure 7-left) and the reproduced smoother ECa map (figure 7-right) of the investigated field can be created with any Geographic Information System (GIS) and geostatistical software packages. The ECa maps of any field shows a difference in ECa values caused by the corresponding response of the soil scanned. Field areas with higher clay or higher organic matter content contribute to the higher ECa values. This shows that a soil ECa map simply tells how soil composition changes across the field, as highlighted by different shades of color for soil ECa zones as in the figure below.

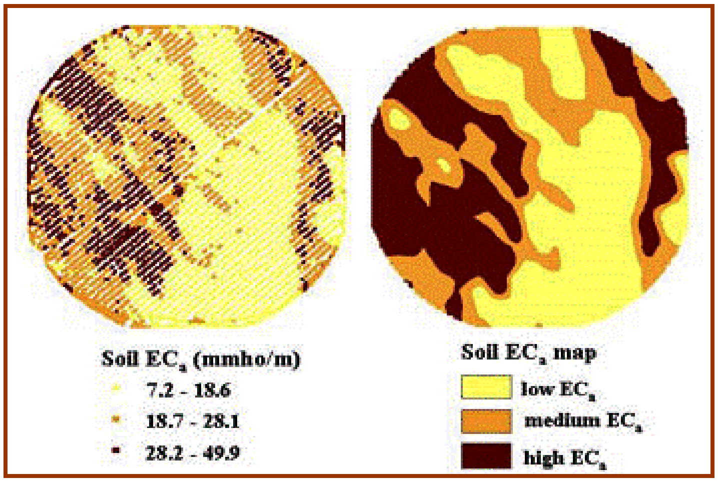

Figure 7 ECa point data gathered with the sensors (left) and reproduced continuous ECa map at the right (Source: After Farahani et al, 2007)

The relationship of soil ECa with the important soil physical properties make the soil ECa map potential to significantly enhance site specific land management. Knowing the pattern of soil composition across the field with the help of ECa maps, farmers and consultants could tailor their soil and crop management decisions to fit the soil pattern rather than assuming that the whole field has a uniform composition. More specifically, such maps could be useful in the interpretation of yield maps, to guide soil sampling, to design on-farm trials, and to help derive input recipes for seeds, nutrients, and crop protection chemicals.

It has also been reported that the ECa changes as soil moisture content changes but the pattern of ECa remains unchanged over years. Since the ECa measurement is mainly influenced by soil physical properties like clay or sand content and these properties are rather constant, a single soil ECa map would be sufficient for many years.

Researchers in SSLM have suggested that there are certain economic and agronomic advantages in using soil ECa maps as a guide to make better management decisions in SSLM. Examples of the most immediate uses of soil ECa measurement and mapping are:

- ❖ Rapid identification of farm field variability;
- ❖ Guidance to smart soil sampling as opposed to random or grid-based soil sampling;
- ❖ Logical placement and interpretation of on-farm tests;

- Development of potential “management zones” for variable rate seeding and chemical application;
- Identification of coarse-textured zones within the field that have low water holding capacity and thus susceptible to crop water stress;
- Identification of crop productivity zones based on relative clay and organic matter contents

7.1.3 Monitoring crop yield

Gathering multi-temporal crop yield information to see the yield dynamics and patterns of the field is very essential for the implementation of any SSLM plans. The yield monitoring methods may differ depending on the farm size, crops, and types of farming system and so on. With the use of recently developed technologies, crop yields can be measured on-the-go more precisely on areas much smaller than the whole field which helps to know the yield variability throughout. Geo-referenced crop yield data are first measured with different techniques and maps are developed using interpolation methods for the use of site-specific management.

There are number of ways to measure crop yields. The major yield measuring approaches are collect-and-weigh method, batch type yield monitoring and instantaneous yield monitoring method.

7.1.3.1 Collect-and-weigh method

This method determines yield for whole farms, for individual fields, and for harvested stripes within fields. Scale-equipped wagons in the field weigh the crop harvest from larger areas. Moisture content in the grains is then measured for the each weighed load and yield is determined. But this method only gives the average yield of the area therefore developed yield maps are not very precise.

7.1.3.2 Batch-type yield monitor

This weighs grains in the grain tank of a combine, a wagon into which the grain is loaded, or as the grain tank of the combine is unloaded. Yield must be calculated using the estimate of the area harvested so it is also not very good for SSLM purposes.

7.1.3.3 Instantaneous yield monitors

This measures and records yield on-the-go. On-the-go yield measurement simply means that the process is continuous as the grain is being harvested. Combine harvesters equipped with yield monitors are widely used to map within-field variation of crop yield (Stafford et al., 1996). Yields from the specific locations are automatically recorded within a field as the combine operates. Most site-specific yield monitors also measure grain moisture content on-the-go. When combined with positioning systems such as DGPS (differential global positioning system), instantaneous yield monitors provide the central data for generating yield maps very suitable for site specific management.

According to Morgan and Ess (1997), the most common instantaneous grain yield monitoring system contains the following major components, which work together to measure the site-specific yield (Figure 8).

- Grain flow sensor
- Grain moisture sensor
- Ground speed sensor
- Header position sensor
- Display console

7.1.3.3.1 Grain flow sensor

Different types of sensors such as impact force sensor, plate displacement sensor, radiometric system; load cell system and volume measurement system can be used. Because of the variation in grain bulk density and moisture content, a mass flow sensor is preferable (Stafford et al., 1996). The sensors are placed in the path of clean grain flow typically mounted at the top of the clean grain elevator or conveyor, which are then sensed by the force of passing grains.

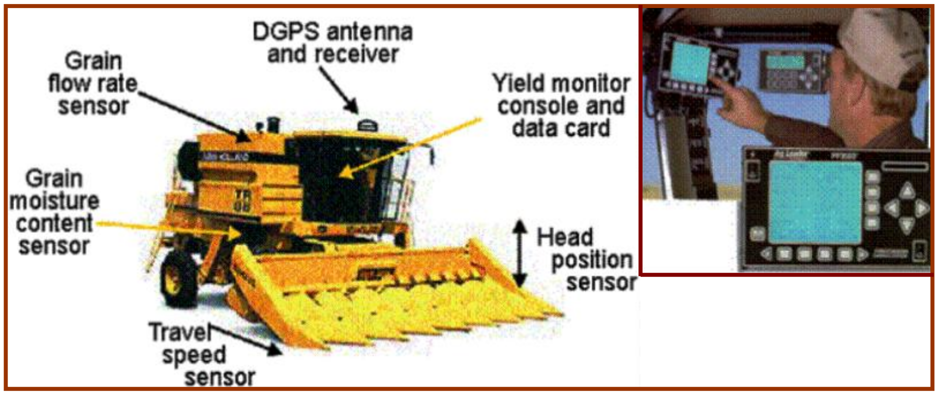

Figure 8 Combine components for yield monitoring and mapping, display console in inset (Courtesy: Purdue University site-specific management center)

7.1.3.3.2 Grain moisture sensor

Moisture content influences grain weight and volume. It can vary widely within field and will certainly vary over time. Most yield monitoring system include some means of measuring grain moisture content automatically, on-the-go. This allows each yield data point to have an associated moisture content value.

7.1.3.3.3 Ground speed sensor

The combine's speed on the field is measured by shaft speed sensor, which measures the rotational speed of the driveshaft from the combine's transmission magnetically. Radar and ultra sonic speed sensing devices are more accurate than shaft speed sensors. The relative motion between the combine and the ground surface produce a frequency shift in the signal that is sensed by the sensor. The GPS based systems calculate groundspeed based on the effect of vehicle motion on the frequency of the radio signal that are received from satellite. The speed estimation accuracy is related to the positional accuracy of a receiver.

7.1.3.3.4 Header position sensor

The header position sensor controls the calculation of harvested acreage. When the sensor detects the header in the raised position, area counting is suspended, even when the combine is in motion and all systems are operating. When the sensor detects that the header has been lowered to a reasonable cutting height, area counting is resumed. The sensitivity of the sensors can be adjusted which permits the combine to turn at field end rows and cross waterways and other non-crop areas without including the area covered in the yield monitor's harvested acreage calculations.

7.1.3.3.5 Display console

The monitor console or the display unit is mounted in the combine cab within easy view of the operator. The console connects all of the sensors that supply information needed to calculate grain yield. It can also receive the data input from the operator for which no sensor is used. This permits the operator to enter the information like field name, cutting width etc. These data are then combined to produce an estimate of crop yield. Calibration is performed to ensure that sensor data and operator input are properly used by a monitor to produce a final output. The monitor can store an extensive data for a season or farm and load. This can be transferred into a PCMCIA card (Personnel Computer Memory Card International Association), which can be used in a personnel computer for further data processing and interpretations.

Yield monitor data reflect systematic and random sources of yield variation including climate and soil-landscape features, localized management-induced yield variation and measurement errors associated with the yield mapping process itself. In spite of their great value in SSLM, yield monitors continue to be improved for use during the mechanized harvest of many crops, including conveyor-harvested crops, such as potatoes, tomatoes, and sugar beets (Hall et al., 1998; Pelletier and Upadhyaya, 1998), peanut (Durrence et al., 1998), cotton (Searcy, 1998; Perry et al., 1998; Gvili, 1998), rice (Iida et al., 1998) and other combine-harvested crops, including wheat corn, and soybeans (Sadler et al, 1998).

7.1.4 Yield variability and its spatial relation to soil properties

Variation in crop yield is the product of interaction of crop genetics and biotic (e.g. insect pests and other pathogens) and abiotic components (e.g. soil factors). Soil properties like available water, texture, bulk density, clay content, organic carbon, pH, subsoil acidity and soil thickness have been found to effect crop yield. Other factors like variation in soil fertility & hydraulic properties, slope position and orientation of the land are also found to affect crop yield. Khakural et al. (1998) reported that corn and soybean yields were less at eroded slopes. Corn yield was positively correlated with horizon thickness & negatively correlated with surface pH. The topsoil thickness, pH, tillage system, growing season and precipitation explained 72% of the variability. Greater crop yields were obtained in foot slope position compared to the back slope & side slope positions in western Iowa (Spomer & Piest, 1982) and west central Minnesota (Khakural et al., 1996). In northern Italy, corn yield variability could be explained by soil nitrate content at the beginning of the growing season, and by spatial differences in soil carbon & nitrogen content (Marchetti et al., 1998). Logsdon et al., (1998) observed that crop yield variability was influenced by stored soil water in rain-fed agriculture. In a drier year soil water storage correlated with both corn and soybean yields. Similarly, studies in laser-leveled, irrigated agricultural land of the arid southwestern USA, Tanji (1996) has shown that soil physiochemical properties such as salinity, soil texture and structure, plant available water, trace elements (particularly boron), and ion toxicity (sodium and chlorine) are the primary soil factors influencing crop yield. Soil organic matter was found as a major source of the most consistent positive influence on corn yields among other soil properties studied in soils with low organic matter than with high organic matter (Bullock and Kravchenko, 2000).

7.2 Analysis of field variability and techniques in attributes mapping

Once variation is adequately assessed the next step is to translate it to the information which can be then employed in SSLM. Different pedometrics and multivariate statistical tools are used to analyze the data by processing with GIS and other spatial techniques. Advanced geostatistical methods are used to analyze the spatial and temporal variability (PenaYewtukhiw et al., 2000). The objectives of the analysis of acquired data is to characterize and manage the key limitations to crop yield in order to obtain higher profits and environmental protection by variable rate application of farm inputs at a within field scale (Mulla and Schepers, 1997).

In SSLM yield and soil attribute data are often acquired as point observations. As mentioned before, such information should be converted to suitable tools like continuous maps to be useful for decision making process. Mostly, yield and soil attribute maps are generated with the spatial interpolation techniques. Interpolation is the procedure of predicting the value of attributes at unsampled sites from measurements made at point locations within the same area or region. Burrough and McDonnell (1998) defined interpolation the procedure of predicting the value of an attribute Z at unsampled site x0 (z(x0)), from measurement made at point locations xi (z(xi)) falling within the same area or region. Methods of interpolation can be divided into two groups namely; global and local interpolation. Global interpolators use all available data to provide prediction for the whole area of interest, while local interpolators use the points of immediate neighborhood. The common interpolation techniques are Thiessen polygons, Triangulation, Natural neighbor interpolation, Inverse function of distance, Trend surfaces etc. These interpolators do not provide precise prediction since they take account of only systemic or deterministic variation, without considering accompanying uncertainty. None of those methods consists of measures to evaluate the quality of predictions. Therefore to overcome such deficiencies, geostatistical methods are popularly used in SSLM research and are discussed in more detail here.

7.2.1 Geostatistical techniques

Geostatistical methods are used to provide suitable tools for analyzing spatial data and their use in SSLM is growing rapidly (Evan et al. 1999; Frogbrook, 1998; Lark et al., 1999; Cassel et al., 2000). Various geostatistical interpolation techniques capitalize on the spatial correlation between observations to predict attribute values at unsampled locations using information related to one or several attributes. The presence of a spatial structure where observations close to each other are more alike than those that are far apart (spatial autocorrelation) is a prerequisite to the application of geostatistics (Goovaerts, 1999). The geostatistical interpolation techniques are known as kriging in honor to D.G. Krige, a South African mining engineer. Many soil and environmental attributes can be interpolated with kriging with best estimates.

The geostatistical techniques are based on the theory of regionalized variables (Matheron, 1965) where, observations at space are looked in stochastic point of view i.e. at each point in space there is not just one value for property but whole set of values with particular probability distribution. This means each point in space (x) there is a variation and therefore a property at the same location is treated as random variable Z(x) with mean μ and a variance of σ2. Regionalized variable theory assumes that the spatial variation of any variable can be expressed as a sum of three major components. These are

1. A structural component, having constant mean or trend;
2. Spatially correlated component, which shows the autocorrelation, known as the variation of regionalized variable; and,
3. A spatially uncorrelated random noise or residual error.

Therefore, the value of random variable Z at x (random function) is given by:

$$Z(x) = m(x) + \varepsilon'(x) + \varepsilon''$$ **Equation (1)**

Where m(x) is the deterministic function of Z at x, $\varepsilon'(x)$ is stochastic, locally varying, spatially dependent residuals from m(x), and ε'' is a spatially independent residual component having mean zero and variance σ2. When a trend or drift is not present, m(x) becomes equal to the mean value of the sampling area, which accounts for the structural effects.

The average or expected difference between two places separated by distance vector h (lag) will be zero:

$$E\left[Z(x) - Z(x+h)\right] = 0$$ **Equation (2)**

Where, Z(x) and $Z(x+h)$ are the values of random variable Z at locations, x and h further away respectively. If it is assumed that the variances of difference depend only on distance vector h,

$$E\left[\{Z(x)-Z(x+h)\}^2\right]=E\left[\{\varepsilon'(x)-\varepsilon'(x+h)\}^2\right]=2\gamma(h)$$ **Equation (3)**

Where, $\gamma(h)$ is the semivariance. If the conditions specified by the intrinsic hypothesis, i.e. stationarity of difference and variance of difference, are satisfied, the previous equation for a value of random variable Z at x can be modified as:

$$Z(x)=m(x)+\gamma(h)+\varepsilon''$$ **Equation (4)**

Therefore semivariance can be indicated as a measure of the structure of the spatial variance of a regionalized variable. The geostatistics can be seen as an attempt to characterize ε' by means of $\gamma(h)$ for accurate predictions. The following formula can be used to estimate semivariance from sample data:

$$\gamma(h)=\frac{1}{2n(h)}\sum_{i-1}^{n(h)}\left[z(x_i)-z(x_i+h)\right]^2$$ **Equation (5)**

Where, $\gamma(h)$, $z(x_i)$ and $z(x_i+h)$ are semivariance at lag (h), attribute value of the regionalized variable Z at spatial location (xi) and location h further away (xi + h), respectively. The n(h) represents the number of observation pairs involved to calculate $\gamma(h)$.

This regionalized variation can be quantitatively described by plotting a set of semivariances against the lag, called the experimental variogram and this provides the essential information about the autocorrelation of the data in order to be used in geostatistical interpolation. The reliability of experimental variogram is affected by the statistical distribution of attribute values and sample size (Webster and Oliver, 2001). Therefore the removal of outliers and at least 50-100 data points are necessary to achieve a stable experimental variogram.

The experimental variogram measures the average degree of dissimilarity between unsampled values and a nearby data value (Deutsch and Journel, 1998), and thus can depict autocorrelation at various distances. Often, spatial variability is direction independent or isotropic where omnidirectional experimental variogram is used. If the spatial variability is direction dependent or anisotropic, directional experimental variogram are used to explain spatial variability of random variables. The experimental variogram is fitted with theoretical mathematical models available such as, linear, exponential, gaussian or spherical and the spherical model is one of the most frequently used one. Figure 9 shows an example of a variogram with fitted spherical model and variogram parameters.

In this figure the semivariance increases with increasing distance then reaches its upper bound and levels off from there to any distance further. The value of $\gamma(h)$ at which the graph levels off is called the sill of the variogram, which is given as C0+C1, where, C0 is nugget variance and C1 is structural variance. The range denoted by 'a' is the finite lag distance (m) where variogram reaches to sill. The observations located within the range are spatially dependent or auto correlated, while observations away from this distance are not spatially dependent or not correlated. The semivariance when h equals zero is nugget (C0) which is an estimate of the residual error or spatially uncorrelated error ε''. The equation of the semivariance gives the numerical value of the variogram parameters, for example for the Figure 9, C0 = 0.915, C1 = 6.039, Sph indicates the spherical type model and 'a'= 125.4 m respectively. Each point in the fitted model was determined by the corresponding number of pairs of the observations.

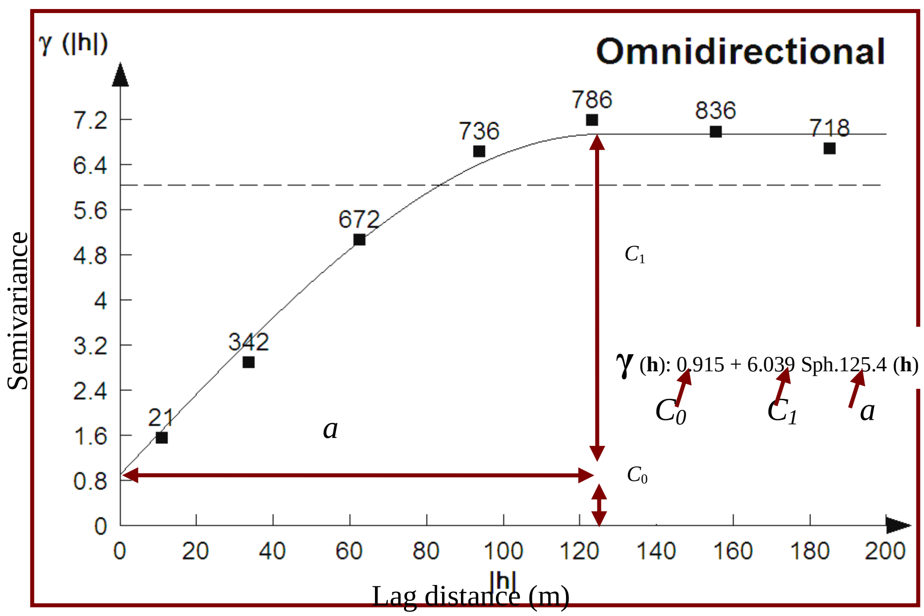

Figure 9 Experimental variogram (dark squares) with fitted spherical model (continuous line) and variogram parameters

Different Kriging techniques have been successfully used for interpolation and selection of a particular method mainly depends on the type of the data or information available. The most commonly used kriging techniques in SSLM are explained as below.

7.2.1.1 Ordinary kriging

The ordinary kriging (OK) is an exact interpolation technique where interpolation value coincides with the value at measured data point. The application of ordinary kriging in soil studies dates back to 1980's (Burgess and Webster, 1980) and during last two decades it has been widely used in various sub-fields of soil science such as soil classification and soil pollution studies. The kriging process is a local interpolation technique where interpolation is done using a subset of observations appears in the neighborhood of the attribute to be predicted. The OK procedure uses the general prediction formula, which is a weighted linear combination of measurement points located within a neighborhood around x0. However, the OK process assumes the local stationary of the mean.

$$Z^{*}{}_{OK}(x_0) = \sum_{i=1}^{n(x_0)} \lambda_i \, . \, z(x_i)$$

Equation (6)

with;

$$\sum_{i=1}^{n(x_0)} \lambda_i = 1$$

Equation (7)

where λi are the weights assigned to n number of observations taken around z(x0). The unbiased weights i.e. to fulfill the condition E[z*(x0) - z(x0)] = 0 are estimated based on the variogram while minimizing estimation variance σ2(x0) i.e. E[{z*(x0) - z(x0)}2] = minimum. The following expression can be derived for the minimum estimation variance in OK process (σ2ok).

$$\sigma^{2}{}_{OK}(x_0) = \sum_{i=1}^{n(x_0)} \{\lambda_i \gamma(x_i - x_0)\} + \psi$$

Equation (8)

where, the quantity ψ is the Lagrange multiplier.

7.2.1.2 Ordinary block kriging

Ordinary point kriging may result in maps that have many sharp spikes or pits at the data points. This is more evident for natural phenomena like soil or water, which show short-range variation (Burrough, 1993). The interpolation of attribute value for a block centered at x0 follows the interpolation of few attribute values (N) within the block z* (xϕ), using point kriging procedure and then weighted averaging those values to estimate attribute value for the block, i.e. Z*(B). The general prediction formula for block kriging can be written as below:

$$Z^*(B) = \frac{1}{N}\sum_{\phi=1}^{N} z^*(x_\phi) = \frac{1}{N}\sum_{\phi=1}^{N}\sum_{i=1}^{n(B)} \lambda_i\phi \, Z(x_{i\phi})$$

Equation (9)

Likewise, the block kriging variance;

$$\sigma^2{}_{bk}(B) = \sum_{i=1}^{n(B)}\left[\lambda_i \, \bar{\gamma}(x_i - B)\right] - \bar{\gamma}(B-B) + \psi$$

Equation (10)

Where, $\bar{\gamma}(x_i - B)$ is the average semivariance between block B, represented by N number of points inside the block (z* (xϕ)) and the observation points (xi). $\bar{\gamma}(B-B)$ is the average within block variance determined by taking average semivariance of N number of (z* (xϕ)).

7.2.1.3 Ordinary co-kriging

Ordinary co-kriging (OCK) is a multivariate extension of OK, in which the estimator is calculated by using simultaneously the auto-correlation between the primary data and the spatial cross-correlation between primary and secondary variables. In standardized cokriging, the secondary variable is rescaled, so that its mean equals that of the primary variable. The cokriging estimator is then written as follows.

$$Z_1^*(\mathbf{x}_0) = \sum_{i=1}^{n_1(x_0)} \lambda_{1i} Z_1(x_i) + \sum_{j=1}^{n_2(x_0)} \lambda_{2j} Z_2(x_j)$$

Equation (11)

With n1(x0) and n2(x0) the number of observations of Z1 and Z2 used for the interpolation and λ_{1i} and λ_{2j} are the weights given to those observations. To eliminate the local means of OCK estimator must be subject to the following two conditions:

$$\sum_{i=1}^{n_1(x_0)} \lambda_{1i} = 1$$

Equation (12)

$$\sum_{j=1}^{n_2(x_0)} \lambda_{2j} = 0$$

Equation (13)

The relatively larger multivariate data bases in SSLM may show correlations with different variables, for example soil clay content and ECa. In such instances co-kriging can be used to improve the map resolution of a primary variable using correlated ancillary data. In order to gain considerable predictive precision with OCK, the correlation coefficient should be > 0.5 (Van Meirvenne, 2004).

7.2.1.4 Regression kriging:

Regression-kriging is a geostatistical approach where the target variable to predict has a non-stationary variance. The spatial trend should be first assessed using linear relationships between the target variable and some spatially continuous predictors or determinants. The residuals to the regression are then spatially interpolated using simple-kriging (the mean of the residuals is assumed to be equal to 0).

The equation of the decomposition of the target variable Z1* is written as below:

$$Z_1^* = \left[A_0 + \sum_j \alpha_j K_j \right] + \varepsilon$$

Equation (14)

Where Z_1^* the target is variable, A_0 is the coefficient at origin of the linear regression between Z_1^* and K; the j determinants of the regression, α_j is the jth coefficient of regression of the jth determinant, and ε is the residual to the regression.

The approach is then:

- To calculate the linear regression on the point dataset, using spatially continuous variables (the determinants);
- To calculate the residuals on the points;
- To apply the coefficients of the regression on the spatially continous determinants,
- To interpolate the residuals using simple kriging, 5/ to add the map of the residuals and the map of the regression.

7.3 Delineation of within-field Management zones

Once the field variability is assessed and their spatial continuity is displayed in the form of a map, the next step is to classify the field variability into some manageable field units in order to practically implement the theory of SSLM. A management zone is a sub-region of a field that expresses a relatively homogeneous combination of yield limiting factors for which a single rate of a specific crop input is appropriate. According to Kvien and Pocknee (2003), management zones are regions of a farm field that are differentiated from the rest of the field for the purpose of receiving individual management attention.

A number of attributes could be used to delineate potential management zones. Fleming and Buschlieter (2002) used remote sensed data to determine site-specific management zones. Stafford et al., (1998) used yield maps to regionalize fields in to management zones. Shater and McBratney (2001) used sorghum yields, SOM and soil potassium level to subdivide fields into homogeneous units. Mulla and Bhatti (1997) concluded that spatial patterns in surface organic matter content and yield maps could be useful in delineating fertilizer management zones. Fraisse et al. (1999) indicated that elevation, soil ECa and slope are the most important attributes to delineate management zones in clay pan soils. Ostergaard (1997) developed management zones for site-specific nitrogen application based on soil type, yield, topography, and aerial photos and producers experience.

Like the attributes to be considered, several procedures have been used to define management zones. Site specific management zones as described by Flemming et al. (2000) and Khosla et al. (2002) were delineated from the variability in color observed in bare soil imagery of conventionally tilled field, farmer's perception of field topography, and farmer's knowledge of past production practices. The variability in bare soil reflectance, and that observed by the farmer, is due, in part, to non-uniform distribution of certain soil properties that influence crop productivity. Kitchen et al. (1998) compared the use of traditional soil surveys and map overlay based on topsoil depth and elevation to delineate management zones. They concluded that map-overlaying method has the potential to delineate management zones compared to the traditional soil surveys and also the outcome of this method completely depends on the user. Fraisse et al. (2001) used principle components analysis coupled with unsupervised clustering algorithm ISODATA (Iterative Self-organizing Data Analysis Technique) procedure to define discontinuous management zones. The fuzzy algorithm has also been used to delineate management zones using yield data and soil attributes. Friddgen et al., (2000) have investigated the clustering performance indices namely Fuzziness Performance Index (FPI), Normalized Classification Entropy (NCE) and Separation Index (SI) to identify the optimum number of management zones using grain yield data. Doerge (2004) suggested different soil attributes as follows that can be used for identifying management zone.

Quantitative, stable	Elevation/topography, SOM, pH or calcium carbonate, soil electrical conductivity, high intensity soil survey maps, surface curvature and hydrological properties
Quantitative, dynamic	Yield monitor data, weed density and distribution, crop canopy appearance or temperature, soil moisture or salinity, soil or plant nitrogen status.
Qualitative, stable	Soil color, first order Natural Resource Conservation Service (NRCS) soil survey maps (1:15,800 scale), immobile nutrients (e.g. phosphorus and potassium), soil pathogen or past patterns, depth to subsoil, soil aeration/drainage status.
Intuitive/historical	Grower knowledge of field characteristics, overall yield pattern and historical practices, soil tilth and quality, past crop rotations, old field boundaries, land leveling and drainage patterns, subsoil characteristics.

Figure 10 Different soil properties that can be used for management zones identification

7.4 Preparation of application maps

After the management zones are identified, application maps are generated for various farm inputs such as tillage intensity, seed rate, fertilizer, pesticides or irrigation application which have been "ground-truthed" to give specific details of inputs required throughout a paddock. The maps are then fed to the Variable Rate Technology (VRT) system which can be used to treat those variable paddocks according to the existing variability. This facilitates the application of site-specific management to achieve its objectives.

The variable rate technology has been employed for application of major plant nutrients such as nitrogen (N), phosphorus (P), and potassium (K), and several other inputs like lime, seed rate, hybrid or variety, pesticides, manure, soil amendments, water and so on in a site-specific basis. Principally, the VRT system uses the following two approaches for its overall functioning:

- Sensor based approach; and,
- Management based approach.

In the sensor based approach, the system measures the desired properties, such as soil and plant properties, using real-time sensors in an on-the-go fashion and controls variable-rate applicator based on the measurements. For the sensor-based approach, a positioning device is not always needed and does not even need application maps (Figure 11). As the machine passes across the field, it measures the required property by the sensor and the response to that specific area in terms of farm inputs application is controlled by the applicator based on the data gathered. The data collection and input application both work simultaneously which is the big advantage of this system.

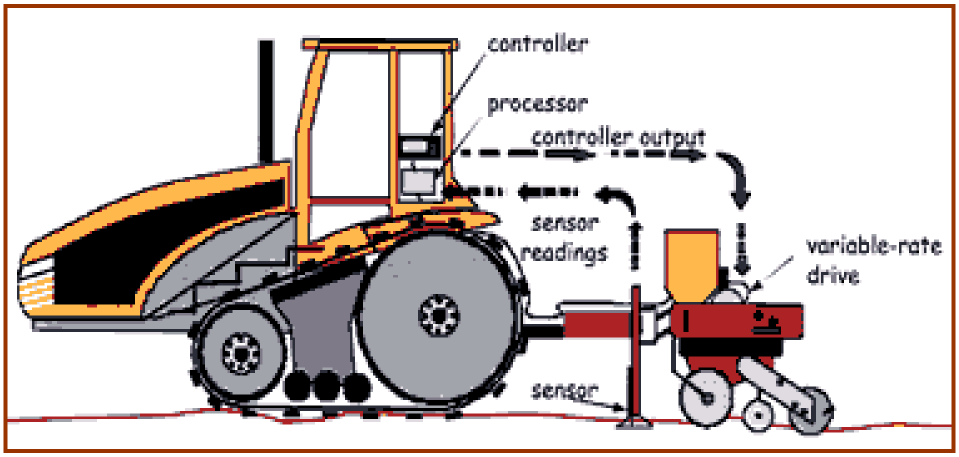

Figure 11 Sensor based variable rate technology (Courtesy: Purdue University site-specific management centre)

However, the management zones based approach is generally easier to implement and are progressed considerably compared to the sensor-based approach. This approach requires grid sampling of a field, laboratory analysis of soil samples, use of yield maps thereafter generating a site-specific map or the application maps and finally using this management zone map to control a variable-rate applicator (Figure 12). A positioning system such as GPS is usually required for this approach.

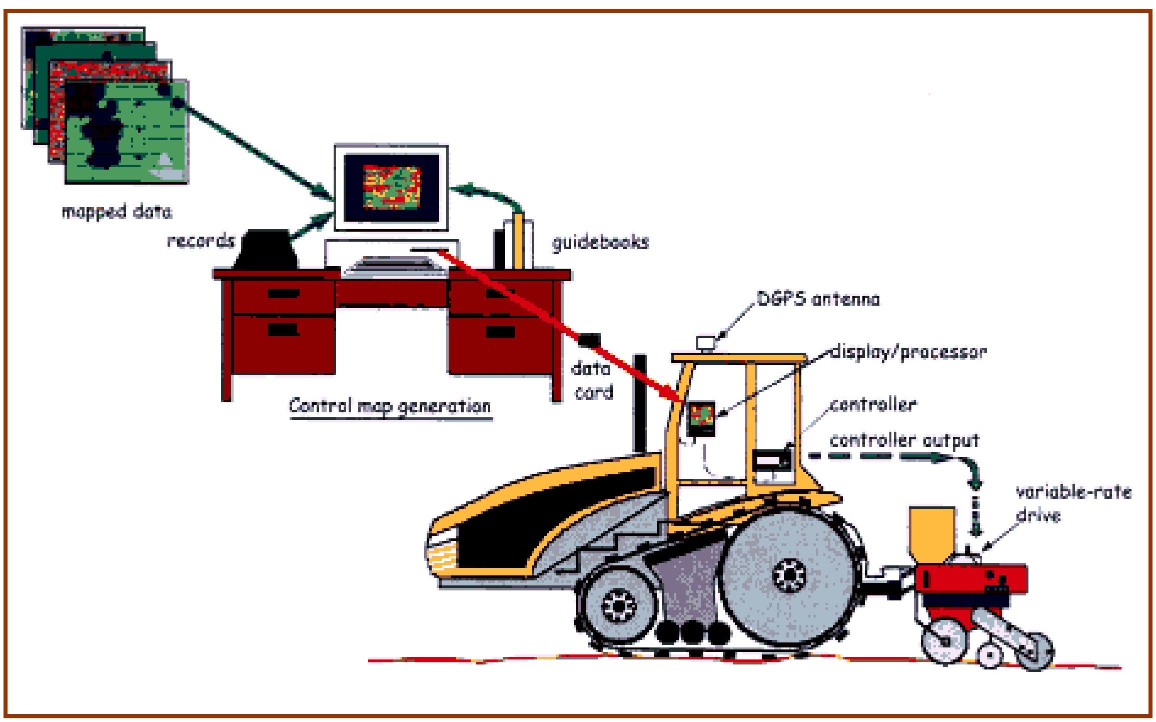

Figure 12 Management zones based variable rate technology (Courtesy: Purdue University site-specific management center)

8 EVALUATION OF SSLM

The evaluation of the performance of SSLM allows for precise tracking and tuning of crop production. There are three important issues regarding the evaluation of SSLM;

1. economics,
2. environment, and
3. technology transfer

Farmers can make economic analysis based on the variability of crop yield in a field to obtain accurate assessment of risk. Comparing the net income or yield and farming efficiency before and after the application of the SSLM, one gets a clear idea how beneficial it was choosing this new farming technology over the conventional method. Judicial agrochemical use, higher nutrient use efficiencies, increased efficiency of managed inputs and increased protection of soils and ground water from degradation and pollution are frequently cited as potential benefits of SSLM to the environment. Technology transfer implies how easily farmers believe and tend to adopt this technology which depends on the communication to the farmers and farmer's willingness to adopt this technology.

9 IMPORTANT PRACTICAL TOOLS IN THE PROCESS OF SSLM

9.1 Remote sensing and its implications in SSLM

Remote sensing refers to the process of gathering information about an object, at a distance, without touching the object itself. Air craft and satellites are the common platforms from which remote sensing observations are made. Current remote sensing technology offers collection and analysis of data from ground-based, atmospheric, and earth-orbiting platforms, with linkages to GPS data, GIS data layers and functions, and emerging modeling capabilities (Franklin, 2001). This has made remote sensing a valuable source of land-cover and land-use information. In agricultural terms; it simply means viewing crops from overhead recording what is viewed, and displaying the image to provide a map of crop condition and health and soil conditions. Those maps could be used as a secondary information source for SSLM. Remote sensing has been a very promising data collection tool for SSLM plans.

Various workers have shown the advantages of using remote sensing technology to obtain spatially and temporally variable information for precision farming. Soil physical properties such as organic matter have been correlated to specific spectral responses (Dalal and Henry, 1986; Shonk et al., 1991). The nitrogen status of crops has also been estimated using remotely sensed data (Blackmer et al., 1995). Yang and Anderson (1996) describe methods to utilize multi-spectral images of vegetated fields for the determination of within-field management zones for application to SSLM. Remote sensing images have been combined with a crop water stress index (CWSI) model to measure field variations (Moran et al., 1997). Remote sensing also can be used in forecasting crop yield. For crops such as grain sorghum, production yields, leaf area index (LAI), crop height and biomass have been correlated with normalized difference vegetative index (NDVI) data obtained from multi-spectral images (Yang and Anderson, 1996). However, in order to get reasonably accurate yield predictions this data must be combined with input from weather models during the growing season (Moran et al., 1997).

9.2 Geo-referencing in SSLM

Since the SSLM is a location specific field management, geo-referencing of soil and yield attribute data is very important in order to follow SSLM. The success of the plan depends on how accurately it identifies the location in the field to be treated with the distinct farm inputs for example. Geo-referencing in SSLM is accomplished with the use of GPS. The Navigation Satellite Timing and Range Global Positioning System, or NAVSTAR GPS, is a satellite based radio-navigation system that is capable of providing extremely accurate worldwide, 24 hour, 3-dimensional location data (latitude, longitude, and elevation). The system has reached the full operational capability with a complete set of at least 24 satellites orbiting the earth in a carefully designed pattern (Figure 13).

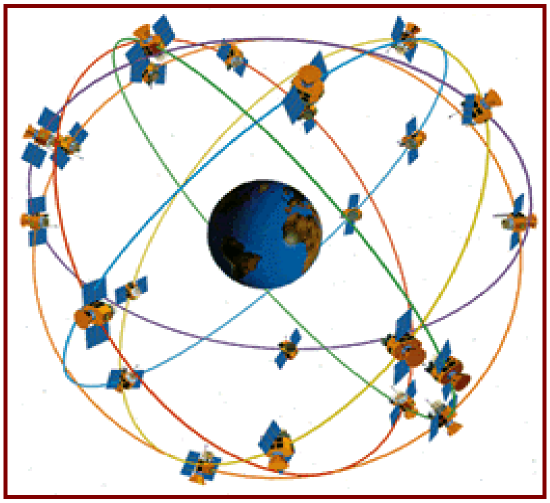

Figure 13 24 Global Positioning System satellites network (Courtesy: www.aero.org)

The overall process of geo-referencing works with certain principle. The position of any point on the earth is determined by measuring distances (pseudo-ranges) from the receiver to at least 4 satellites. The GPS receiver knows where each of the satellites is at the instant in which the distance was measured. These distances will intersect only at one point, the position of the GPS receiver (antenna). The GPS receiver performs the necessary mathematical calculations, then displays and/or stores the position, along with any other descriptive information entered by the operator from the keyboard. Because of its higher precision, differential GPS (DGPS) technique is popularly used in SSLM. DGPS enables the user to improve standard position fixes and also to remove the effects of selective ability and some other sources of error. Figure 14 shows the components of DGPS and its working principle.

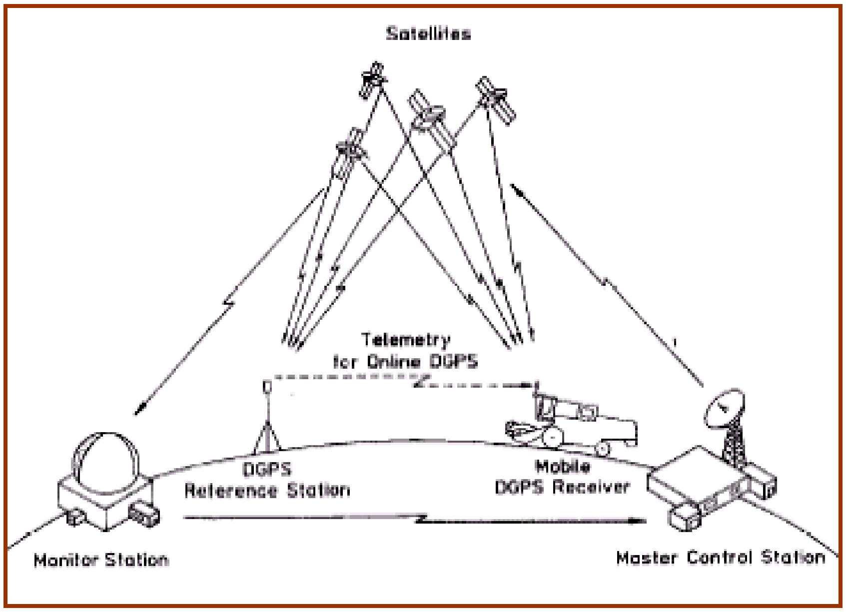

Figure 14 Configurations of differential global positioning system (Source: Reitz and Kutzbach, 1996)

9.3 GIS as a tool for Data processing in SSLM

GIS is a computer-assisted system for the acquisition, storage, analysis and display of geographical data. The system consists of hardware and software used for storage, retrieval, mapping, and analysis of geographic data. With GIS, it is possible to produce a map output on a screen or hardcopy devices, converting paper based maps into digital form, managing and analyzing attribute data, analyzing data based on their location. Databases related to SSLM such as soil data from grid sampling, yield monitoring data and other tabulated databases describing the characteristics or qualities of these features are usually very huge and GIS is capable of handling such multivariate databases efficiently. GIS can process the data from different sources like data from satellites and aerial photographs, digital maps and other digital data and tabular information giving typically map or sometimes tabular output with new information on it (Figure 15).

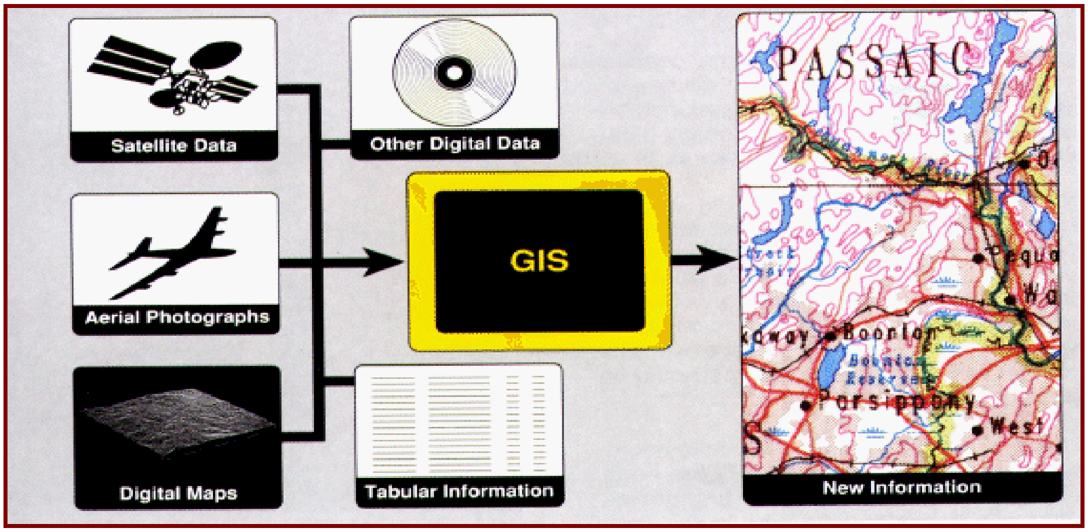

Figure 15 Data integration through geographical information system and production of a required map (Convey, 1999)

New GIS software versions are incorporated with geostatistical analysis tool for accurate analysis of spatial data e.g. Arc GIS, Idrisi. Yield maps by themselves are probably not especially useful unless they are compared with other attributes such as, soil moisture, soil texture etc. and GIS helps here by bringing those data bases in the same coordinate system and comparing them to make decisions. Other implications of GIS are for example; display showing a contour map of a field against a colored yield map makes it easy to see how yield relates to elevation. Sometimes data from multiple years is used together to see whether problem areas are growing or shrinking. Images taken from satellites or airplanes can be imported to a GIS and used to detect weeds, irrigation problems, or other plant stress.

10 AN EXAMPLE OF SSLM APPLICATION IN THE BELGIAN POLDER FIELD

In order to clarify the concept and applications of SSLM, we try to show with an example how the attribute data can be gathered till the final SSLM application maps preparation through different processes in between. This example has been taken from the research done by the department of soil management of the Ghent University in Belgium in 2004-2006 to see how the site specific crop management principles can be employed to track the farming decision in a small sugar beet field of the polder area in Belgium.

10.1 Site description

The agriculture fields in the Belgian polder areas are very fertile agricultural lands consisting of alluvium and these lands were reclaimed by artificial drainage. Our investigated field in the polders covers about 10 ha area in Watervliet in the Northwest East-Flanders, Belgium. The field is characterized by its flat topography with the elevation of ±3 m above mean sea level with a crop rotation of potato-winter wheat-sugar beets-winter wheat; typical for the polders. No water logging conditions were noticed in the investigated area since the ground water table was found at a depth of 1.2 m. The field was assumed to be under cultivation since the 16th century.

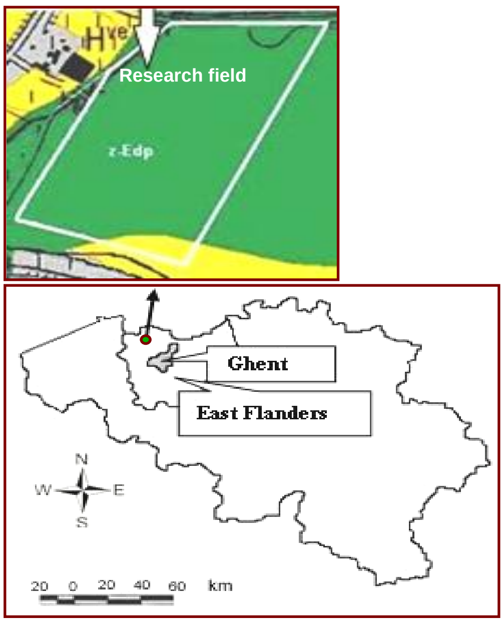

Figure 16 Location of study area in Belgium and on the top, investigated area in the Belgian soil map (1:20,000)

The soil type is *z-Edp* (i.e. light clayey topsoil with un-deep sandy substrate, moderately wet, no profile development) according to the Belgian soil classification system. According to Soil Taxonomy (USDA, 1975) the soil was classified as coarse-loamy, illitic, calcareous, mesic, Aquic Udifluvents. The top 110 cm are calcareous Holocene deposits, whereas the deeper layers are Pleistocene sediments with a peaty top layer. It is mentioned that the soil has originated from different parent materials as evidenced by soil textural variation between different soil horizons. Between the depth of 40 and 47 cm a lithologic discontinuity occurs and the textural composition changes from loam to sandy loam and loamy sand.

10.2 Field ECa survey and preparation of ECa map

An intensive ECa survey of this field was conducted by the Research group of the department to understand the spatial variability of field ECa with EM38DD sensor. ECa data on each observation point were recorded simultaneously by the vertical and horizontal dipole modes of the sensor. The GPS guided location and ECa data were recorded between 2 seconds interval corresponding to measurement distance of 2 meters along the measurement transects of 5 meters apart. Drifts in measurement were controlled by recalibrating the sensor in a determined reference point where measurements were made in hourly interval for checking the stability of the sensor.

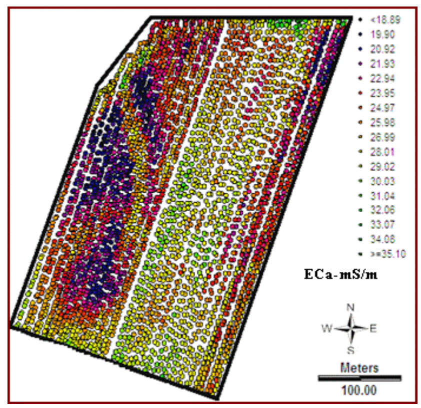

Figure 17 Mobile system in field ECa survey (inset -EM38DD sensor, field computer and GPS receiver) on the left and trace of ECa survey with measurement points (right)

After removing repeated measurement points and points outside the interested field boundary, 3498 geo-referenced ECa_v (vertical) and ECa_h (horizontal) measurements were retained for subsequent analysis. The trace of ECa measurement recorded during the field survey is displayed in the figure 17 above.

The continuous map of ECa was prepared using ordinary kriging technique- point kriging. Experimental omni-directional variogram for both vertical and horizontal ECa data were calculated using GSLIB (Geostatistical Software Library) program and the best fitted mathematical models (spherical models for both) were selected subsequently.

These ECa maps as depicted in Figure 18 show the variation of ECa recorded by the EM388DD throughout the field for both vertical and horizontal orientations. The lower conductivity values were recorded towards the left side of the field whereas most of the field area corresponded to moderate to higher ECa. These spatial variations of ECa explained the variation of soil properties that influenced soil ECa. This spatial variability pattern identified by the equipment served as a guidance to identify field locations to take soil samples. Soil samples were collected for both topsoil (0-40 cm) and subsoil (50-80 cm) depth in each identified location to see the variability in both the depths. Sufficient care was taken while locating the points in order that our 78 points truly represent the whole surveyed area as in figure 19.

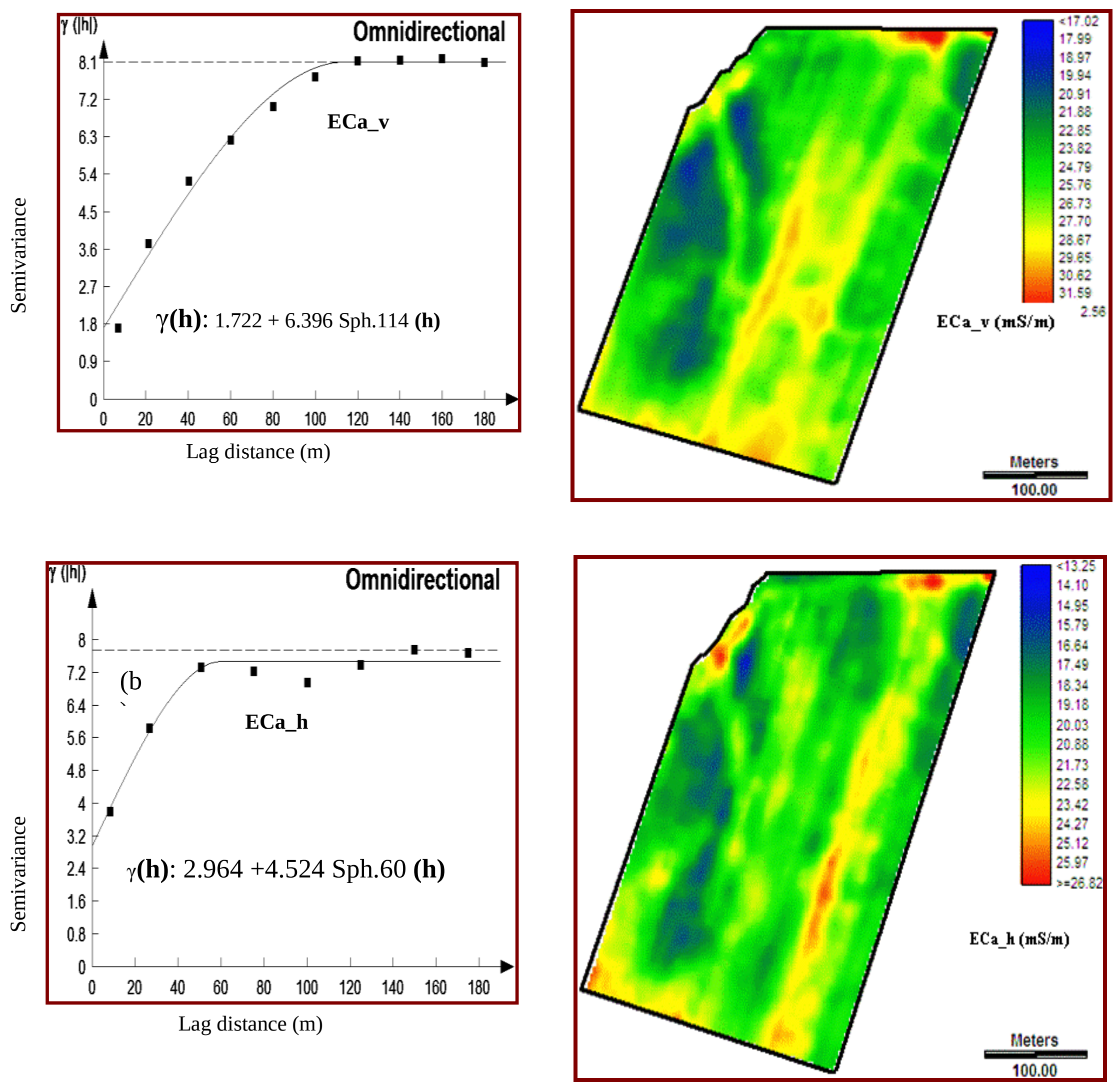

Figure 18 Experimental variogram (black squares) and fitted spherical models (continuous line) and corresponding continuous map developed

The soil samples were than analyzed for their sand, silt and sand content, soil organic matter and soil moisture. All the properties thus measured were compared with the corresponding ECa value in order to see either of their effect on measured ECa. It has been found that most of the subsoil properties were correlated with the ECa data gathered from vertical orientation of the sensor whereas topsoil properties were more correlated with the ECa data response of the horizontal dipole. As suggested by McNeill (1992), the horizontal dipole had dominant response of the shallow depth or the top layer and vertical dipole was more responsive to the deeper layers. The ratio of these two gave the heterogeneity of the profile.

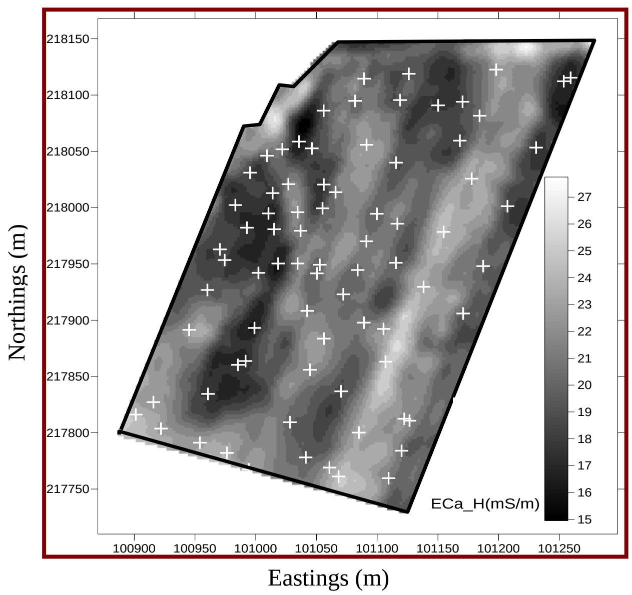

Figure 19 Soil sampling location identified on the field ECa map

Comparing soil properties from both top and subsoil layers (figure 20) it can be noticed that subsoil properties indicates the presence of higher variability. The higher CVs of almost all properties in subsoil depths revealed that subsoil is highly heterogeneous than topsoil which have lower CVs for those properties. This can also be inferred as most of the variability recorded in ECa values might be influenced by the heterogeneous subsoil. This difference in soil properties between the layers especially of the textural fraction that governs many physiochemical and biological soil properties might show differential influence in plant growth and development.

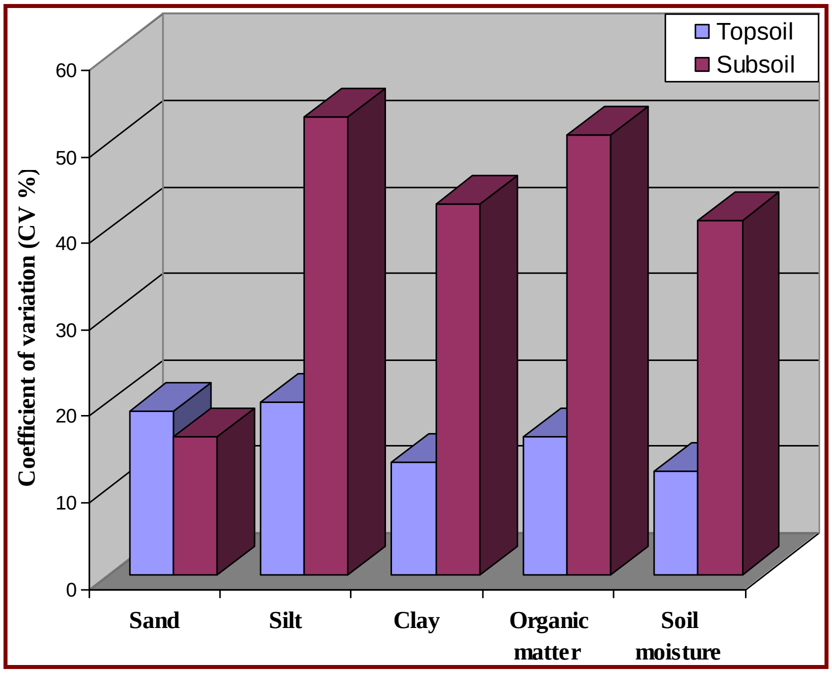

Figure 20 Coefficient of variation of measured soil properties

10.3 Identification of potential management zones and differential input treatments

As described earlier, potential management zones are the more homogeneous areas in the field which receive similar input applications or management. The management zones of our study area were identified by taking in to account the measured ECa in the field. As suggested by principle component analysis, ECa data was the major property affecting over all field variability (>70% for factor 1 and 2) hence it was used in fuzzy classification. It is also because we have very densely measured ECa data and data gathering was also very easy and efficient.

Based on this ECa values as input, we classified the field into different homogeneous parts. Fuzzy classification suggested two distinct classes for which the fuzziness performance index (FPI) and normalized classification entropy (NCE) values were found to be at minimum i.e. 0.1131 and 0.1365 respectively for the fuzziness exponent of 1.3 as compared to other classes like class 3, 4 and 5 which showed higher values for those parameters.

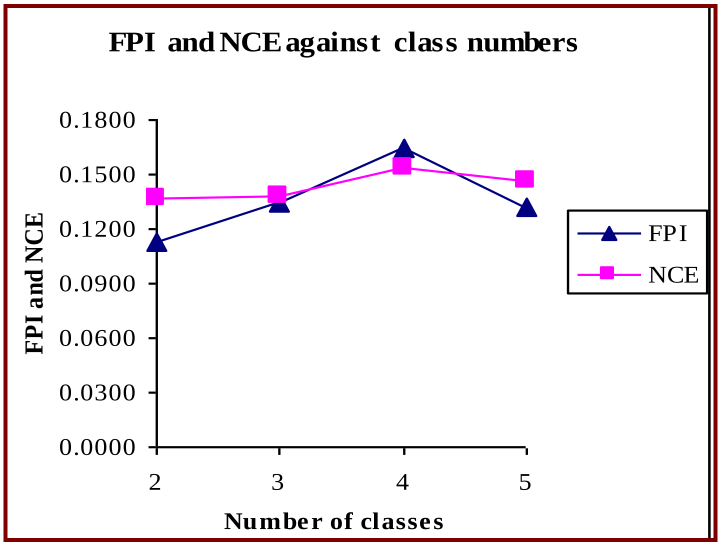

Figure 21 Fuzziness Performance Index and Normalized Classification Entropy plotted against different number of classes

The map of the Figure 22 shows the two identified management zones for the investigated area derived from fuzzy k-means. Since the ECa was highly influenced by subsoil textural variability, we believed that the classes it determined also preserved this important information. As the topsoil is almost homogeneous, the clay content between the management zones was quite similar giving the textural class "Loam" for both management zones according to USDA textural triangle whereas the subsoil was different between them. It was "Loamy Sand" for management zone 2 and "Sandy Loam" for management zone 1. Hence, these zone 1 and zone 2 were named as 'Loamy area' and 'Sandy area' respectively.

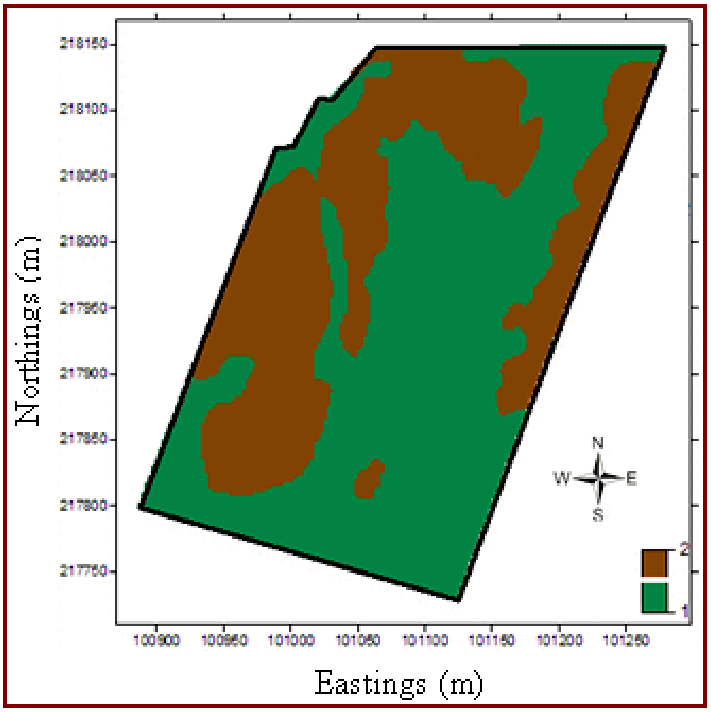

Figure 22 Management zones derived from fuzzy k-means classification (zone 1- Loamy area; and zone 2-Sandy area)

The management zone 1 is of about 5.85 ha area having comparatively higher subsoil clay content than zone 2 which consists of higher subsoil sand content and covers about 4.13 ha area of the field. The chemical fertility of zone 1 can be considered as superior due to higher clay content for both the top and subsoil. This favors in reserving more nutrient elements and moisture to supply to the plants. Unlike management zone 1, the sandy nature of the subsoil of management zone 2 favors relatively higher drainage causing leaching of plant nutrients especially very mobile nitrate anion and other cations like potassium in the polder area. Due to lower water holding capacity of the sandy material, plant roots might experience short term drought during dry summer months which would affect evapotranspiration minimizing the accumulation of photosynthate. Plant roots growing in the sandy part might also experience physical resistance imposed by sand fractions which would not be the case with fine texture rich loamy area where roots proliferate much exploiting the root zone at their maximum.

This demarcation of management zones is very much beneficial for the implementation of site-specific crop management planning especially for the management of nitrogen and organic matter in the investigated field. Maximizing the organic matter input and frequent split application of nitrogen to reduce leaching loss might be the useful practices to manage sandy area for higher yields. But very deep tillage should not be practiced there otherwise less fertile sandy subsoil would come up on the top affecting topsoil fertility negatively. Therefore, instead of uniform application of inputs resources, site-specific application based on management zone characteristics can be recommended to increase income with reduced loss and negative environmental impacts. But before this, the cost-benefit analysis has to be done otherwise the whole site-specific management program would be of less interested to the farmers.

11 CONCLUSION

The SSLM is comparatively a new farming technology for the sustainable use of farm resources for agriculture production, however, technology driven this farming technology is still in its infancy. Better understanding of within-field variability and trailing the farm management inputs according to the underlying variability is the main principle of the SSLM. Moreover, this farming technology is intended to facilitate management of farm resources in an economic and ecologically-efficient way in the spatial and temporal domain. With the advance of farming technology such as mechanization and automation in agriculture in the last few decades, site specific management has been a major part of the farming system of the developed countries but adoption of this hi-tech demanding farming among the farmers of developing countries is rather very slow and still needs a lot of extension efforts and farmers' motivation. Moreover, the main current researches which are undertaken deal with finding new sensors which are capable to capture and explain quantitatively the different soil properties like hyperspectral or gamma-ray sensors. Sensor integration is then a high research topic and is the object of two European FP7 calls (ISOIL and DIGISOIL). Results will be out in 2011.

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Abstract

To meet the growing need of people for increasing farm income and to minimize the negative environmental impact of today's farm practices, a new farming concept has been evolved where inputs are fine tuned and optimized according to the local field variability such that yield increment is achieved with a minimum harm to the local environment. This farming concept is different than the traditional farming system and can be highlighted as a precision agriculture system or more specifically termed as site specific land management (SSLM) which takes the advantage of recent technological developments and their uses in agriculture. It operates by matching resource application and agronomic practices with soil attributes and crop requirements as they vary across a field leading to the overall economic and environmental benefits. This report explains in brief a general concept and principle of this eco-friendly farming approach with some common procedures to be followed while planning of SSLM in any area. It also provides an example of applying this farming concept in a small area in Belgium and recommends some land and crop management practices. Finally it also emphasizes a need of more research activities to advance it and extend this technology to the farming community for all possible benefits. We believe this report can be helpful to the farm managers and soil researchers who are not very much familiar with the concept of SSLM and might show a general ways in adopting and applying this farming technology.

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