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DEVELOPMENT OF A TRAINING PROGRAM FOR ENHANCING THE USE OF ICT TOOLS IN THE IMPLEMENTATION OF PRECISION AGRICULTURE

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Training package 2

Remote sensing and GIS applications in agriculture

Tutor instructions

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Contents

1 Soil variability

(Slide 2-8 from document *LectureGIS.pptx*) [1,2]

Conventional agriculture treats an entire field uniformly with respect to the application of fertilizer, pesticides, soil amendments, or other inputs. However, soil is spatially heterogeneous, with most soil chemical and physical properties varying significantly within just a meter. Soil spatial heterogeneity is one of several factors that cause within-field variation in crop yield. Other spatially and/or temporally variable factors influencing within-field variation in crop yield include man-related (e.g., irrigation management, compaction due to equipment, etc.), biological (e.g., disease, pests, etc.), meteorological (e.g., humidity, rainfall, wind, etc.), and topographical (e.g., slope, aspect, etc.) influences. The inability of conventional farming to address within-field variations in these factors not only has a detrimental economic impact due to reduced yield in certain areas of a field, but also detrimentally impacts the environment due to over applications of agrochemicals and wastes finite resources.

Precision agriculture, or more appropriately site-specific crop management, has been proposed as a means of managing the spatial variability of edaphic (i.e., soil related), anthropogenic, topographical, biological, and meteorological factors that influence crop yield with the aim of increasing profitability, increasing crop productivity, sustaining the soil-plant environment, optimizing inputs, and/or minimizing detrimental environmental impacts. Site-specific management units (SSMUs) are spatial domains of soil that can be managed similarly to optimize yield by accounting for variability.

1.1 Digital Soil Mapping

Definition:

“The creation and the population of a geographically referenced soil database generated at a given resolution by using field and laboratory observation methods coupled with environmental data through quantitative relationships.”

- The International Working Group on Digital Soil Mapping (WG-DSM)

“Production of soil class or property maps using GIS and/or Remote Sensing software” – anonymous

Digital soil mapping (DSM) represents “the creation and population of spatial soil information systems by the use of field and laboratory observational methods coupled with spatial and non-spatial soil inference systems” [3]. Soil science, geographic information science, quantitative methods (statistics and geostatistics) and cartography are combined within the DSM framework. DSM methods are used to estimate the spatial distribution of soil classes (e.g., soil series) and/or soil properties (e.g., soil organic matter), and can be employed at various scales (from individual fields to countries), and have proven valuable for developing more quantitative, more accurate, and more precise soil maps.

1.2 Digital Soil Mapping Vs Conventional Soil Mapping

The use of geospatial techniques for mapping soils is broadly covered by the term “digital soil mapping” (DSM). Digital soil mapping is defined as the creation of geographically referenced soil databases based on quantitative relationships between spatially explicit environmental data and measurements made in the field and laboratory. Use of digital soil mapping techniques has progressed as soil scientists have adopted the latest tools to assist in the mapping process. The process of making an inference about a landscape segment (e.g., a soil map unit) from a few point-based observations using the operative soil-forming factors is “modeling.” Whether the soil map is produced using nothing but a bucket auger and an aerial photo or using geospatial software, the process is a modeling operation. The use of DSM methods is increasing over time and will eventually cease to be considered distinct, novel techniques. [4]

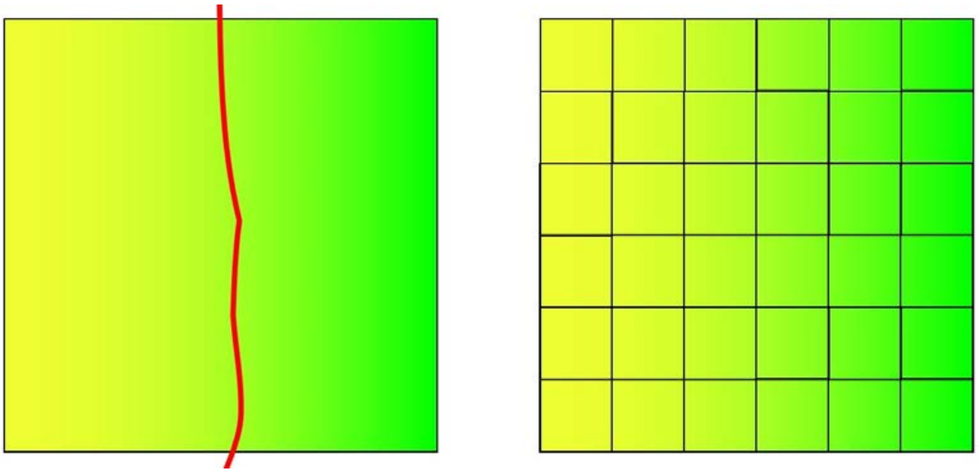
The digital soil map is a raster-based map composed of 2-dimensional cells (pixels) organized into a grid in which each pixel has a specific geographic location and contains soil data. Digital soil maps illustrate the spatial distribution of soil classes or properties and can document the uncertainty of the soil prediction. Digital soil mapping better captures observed spatial variability and reduces the need to aggregate soil types based on a set mapping scale. Digital soil mapping can be used to create initial soil survey maps, to complete MLRA update projects, and generate soil interpretations. It can facilitate the rapid inventory, re-inventory, and project-based management of lands in a changing environment.

The availability and accessibility of geographic information systems (GIS), global positioning systems (GPS), remotely sensed spectral data, topographic data derived from digital elevation models (DEMs), predictive or inference models, and software for data analysis have greatly advanced the science and art of soil survey. Conventional soil mapping now incorporates point observations in the field that are geo-referenced with GPS and digital elevation models visualized in a GIS. However, the important distinction between digital soil mapping and conventional soil mapping is that digital soil mapping utilizes quantitative inference models to generate predictions of soil classes or soil properties in a geographic database (raster). Models based on data mining, statistical analysis, and machine learning organize vast amounts of geospatial data into meaningful clusters for recognizing spatial patterns.

A significant amount of the data used in digital soil mapping can be archived in a digital format in a GIS, so the expert knowledge used to predict soil distribution on the landscape is retained. Objective sampling plans can be implemented to statistically capture variability of the landscape, represented by digital environmental covariates (environmental data representing soil forming factors). The most exciting aspects of digital soil mapping relate to the ability of depicting smaller segments of the landscape for traditional soil classes, continuous representation of physical and chemical properties in multiple dimensions and the associated generation of raster layers representing respective uncertainties. These are capabilities that will allow soil scientists to more completely and thoroughly represent their soil knowledge to users than the current vector model.

1.3 Digital Soil Mapping in a Nutshell

- Digital soil mapping is the generation of geographically referenced soil databases based on quantitative relationships between spatially explicit environmental data and measurements made in the field and laboratory [5].
- Digital soil mapping is the prediction of soil classes or properties from point data using a statistical algorithm.
- The digital soil map is a raster composed of 2-dimensional cells (pixels) organized into a grid in which each pixel has a specific geographic location and contains soil data.
- In conventional mapping, the primary question is “Where is the boundary between two soils?” and the focus is on those marginal areas (left figure below).
- In digital soil mapping, the central concept is well defined with variation expressed across the landscape (right figure below).



- Digital soil maps illustrate the spatial distribution of soil classes or properties and can document the uncertainty of the soil prediction.
- Digital soil mapping can be used to create initial soil survey maps, refine or update existing soil surveys, generate specific soil interpretations, and assess risk [6].
- It can facilitate the rapid inventory, re-inventory, and project-based management of lands in a changing environment.

1.4 NCSS Digital Soil Mapping

The National Soil Survey Center – Geospatial Research Unit has identified DSM as an important area of focus in support of soil survey activities. Numerous DSM research projects have been supported by the GRU. Numerical classification (hierarchical and fuzzy), spatial and temporal interpolation (geostatistics, wavelets), sampling design (model vs. design based), statistical analysis (visualization, ordination, regression, and classification), uncertainty analysis (error propagation, accuracy assessment), and incorporation of auxiliary data (proximal and remotely sensed imagery, soil-terrain modeling) are among the methods used to develop predictive maps of soil classes and soil properties.

1.5 Soil variability. Example, Electrical conductivity

A researchers team investigated the application of detailed airborne images and a resistivity soil sensor (Veris 3100) to detect soil and crop spatial variability to assist in orchard management. [7]

The case study was carried out in a peach orchard (Prunus persica) located in Lleida (Catalonia), which is the leading peach production area in Spain and also one of the most important in Europe. The study area suffered land transformations in the 0s decade to enlarge fields and changed from rainfed arable crops to irrigated orchards.

The Electrical Conductivity survey was done with a Veris 3100 ECa surveyor implement (Veris Technologies Inc. Salina, Kansas, USA). Veris 3100 uses two Electrical Conductivity (EC) arrays to map the 0-30 cm (shallow ECa) and 0-90 cm (deep ECa) soil depths simultaneously. Data was georeferenced by means of a Trimble AgGPS332 receiver with EGNOS differential correction in geographic coordinates WGS84 (EPSG 4326).

It was demonstrated that, in a relatively small orchard, an important spatial variation of soil properties and plant vigour can be found, which can justify the application of Precision Agriculture techniques. The results of the ECa survey and soil sampling showed that the land transformation carried out starting in the 1980 decade to enlarge fields could have altered the spatial distribution and continuity of soil properties.

Overall, the results suggest that PA strategy may be appropriate because of the spatial structures of EC and NDVI variables. Nevertheless, and because of the lack of relationship between EC and NDVI, it is better to propose two types of management zones, depending on the objective of the action to be carried out. One type of management zones would be delineated according to the shallow EC classes, which would mainly serve to improve water retention capacity through amendments with organic matter and more frequent irrigation; and to improve natural drainage. And the second type of management zones would be delineated according NDVI classes, which would serve as reference to regulate tree vigour and yield through different actions such as pruning, application of growth regulator or fruit thinning.

2 Pest management

(Slide 10-14 from document *LectureGIS.pptx*)

2.1 Integrated Pest management

“Integrated pest management means careful consideration of all available plant protection methods and subsequent integration of appropriate measures that discourage the development of populations of harmful organisms and keep the use of plant protection products and other forms of intervention to levels that are economically and ecologically justified and reduce or minimise risks to human health and the environment. 'Integrated pest management' emphasizes the growth of a healthy crop with the least possible disruption to ago-ecosystems and encourages natural pest control mechanisms.” [8]

Principles

1. The prevention and/or suppression of harmful organisms should be achieved or supported among other options especially by:
    - Crop rotation,
    - Use of adequate cultivation techniques (e.g. stale seedbed technique, sowing dates and densities, under-sowing, conservation tillage, pruning and direct sowing),
    - Use, where appropriate, of resistant/tolerant cultivars and standard/certified seed and planting material,
    - Use of balanced fertilization, liming and irrigation/drainage practices,
    - Preventing the spreading of harmful organisms by hygiene measures (e.g. by regular cleansing of machinery and equipment),
    - Protection and enhancement of important beneficial organisms, e.g. by adequate plant protection measures or the utilization of ecological infrastructures inside and outside production sites.

2. Harmful organisms must be monitored by adequate methods and tools, where available. Such adequate tools should include observations in the field as well as scientifically sound warning, forecasting and early diagnosis systems, where feasible, as well as the use of advice from professionally qualified advisory.
3. Based on the results of the monitoring the professional user has to decide whether and when to apply plant protection measures. Robust and scientifically sound threshold values are essential components for decision making. For harmful organisms threshold levels defined for the region, specific areas, crops and particular climatic conditions must be taken into account before treatments, where feasible.
4. Sustainable biological, physical and other non-chemical methods must be preferred to chemical methods if they provide satisfactory pest control.
5. The pesticides applied shall be as specific as possible for the target and shall have the least side effects on human health, non-target organisms and the environment.
6. The professional user should keep the use of pesticides and other forms of intervention to levels that are necessary, e.g. by reduced doses, reduced application frequency or partial applications, considering that the level of risk in vegetation is acceptable and they do not increase the risk for development of resistance in populations of harmful organisms.
7. Where the risk of resistance against a plant protection measure is known and where the level of harmful organisms requires repeated application of pesticides to the crops, available anti-resistance strategies should be applied to maintain the effectiveness of the products. This may include the use of multiple pesticides with different modes of action.
8. Based on the records on the use of pesticides and on the monitoring of harmful organisms the professional user should check the success of the applied plant protection measures.

Reasons for surveying [9]

There are many reasons for surveying pests. some of them are:

- to develop a list of pests or hosts present in an area
- to demonstrate a pest-free area (the absence of a particular pest in an area) or places of low pest prevalence for trade purposes

- to develop a baseline list of pests before ongoing monitoring for changes in pest status
- for pest management and control
- for early detection of exotic pests
- for early detection of established organisms becoming pests
- to delimit the full extent of a pest following an incursion
- to monitor progress in a pest eradication campaign.

European and Mediterranean Plant Protection Organization (EPPO) is the organization which coordinates numerous aspects of plant protection across most of the European countries. EPPO has produced a number of standards on phytosanitary measures and plant protection products. While these standards need apply only to dealings with the European Community, they also provide insight into the quarantine barriers in use. Some of the standards provide a list of pests and information about their control for different crops and about identify cation in the field.

2.2 Pest management. Weeds control. Example 1

Assessing the potential of images from unmanned aerial vehicles (UAV) to support herbicide patch spraying in maize [10]

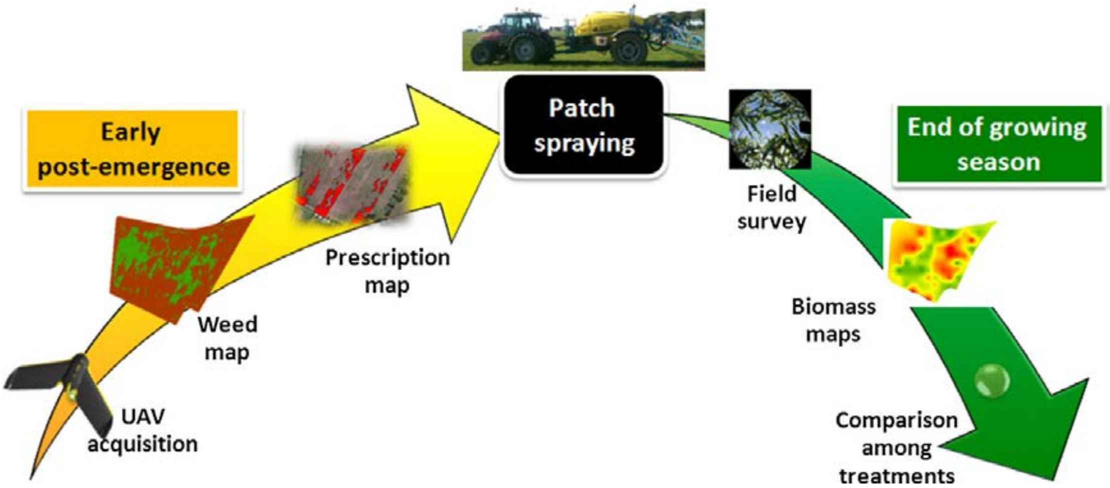
Weed patch detection within the field is the key to applying a patch-spraying system. site-specific weed management (SSWM) requires accurate information on the spatial distribution of weeds. Field scouting coupled with the application of geostatistical techniques could yield accurate weed maps, but this approach is not feasible outside research contexts, being time consuming and expensive.

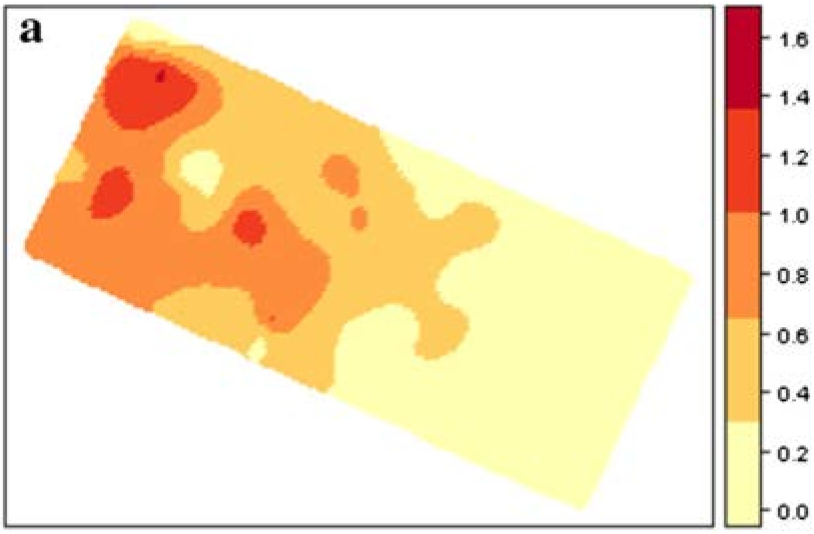
Sensor technologies (spectrometers, fluorescence sensors and digital cameras) and differential global positioning systems (DGPS) can be coupled to obtain information about variation of weed populations within a field, both using proximal (on-the-go sensors mounted on the tractor) and remote sensing instruments.

The use of unmanned aerial vehicles (UAVs) with low altitude flights, provides images with a very high spatial resolution (<50 mm), which are less expensive and have fewer logistic constraints as compared to manned airborne data collection.

The goal of the present work is to assess the feasibility of SSWM based on weed maps from images acquired from UAVs, encompassing the whole process leading to variable rate herbicide application, in an operational context. The steps were to acquire images from UAVs early in the silage maize crop to detect weed spatial distribution within four fields in Central Italy. The weed maps derived from UAV data were used to evaluate two (2014) or

three (2015) post-emergence herbicide application strategies: (i) untreated control, (ii) uniform blanket application, and (iii) patch spraying according to the prescription map.





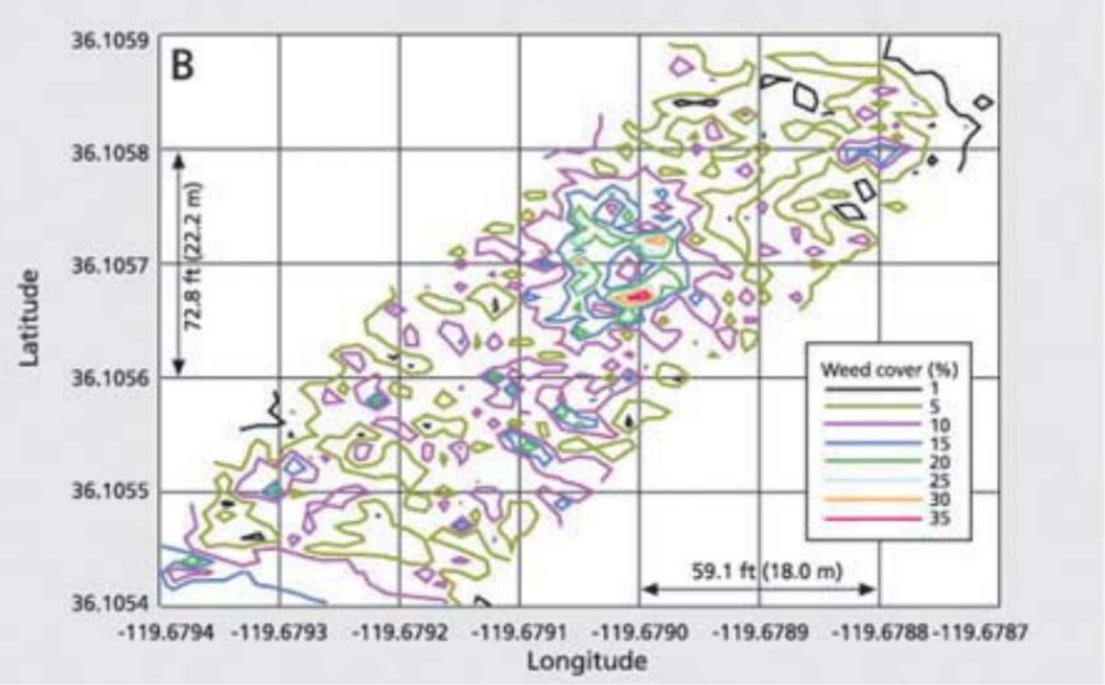
Weed biomass (t ha^{-1})

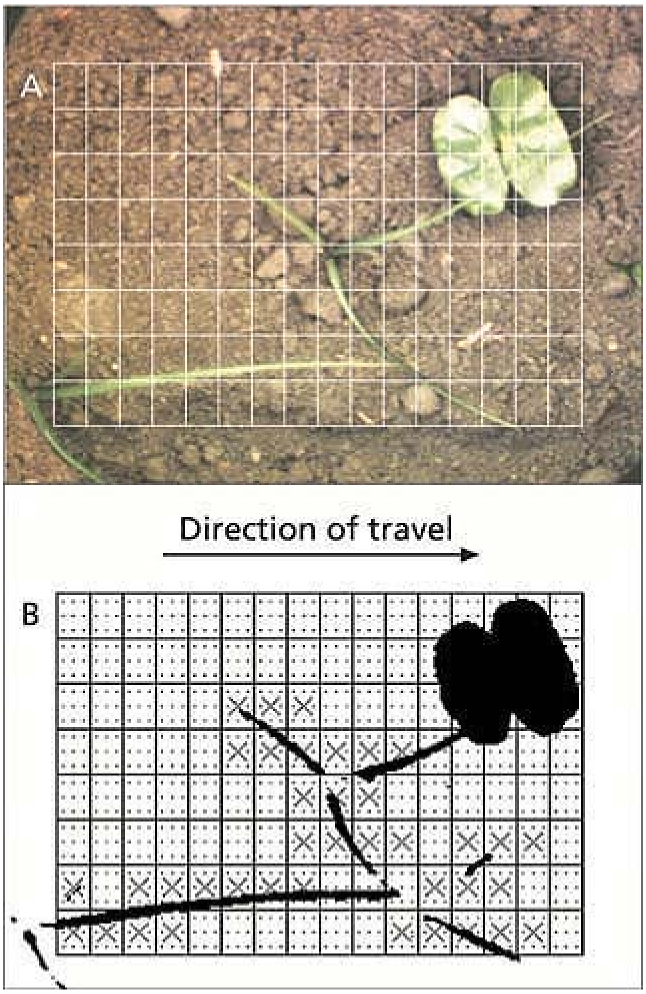
The results obtained in the experiments carried out showed that image data acquired from a UAV could be used operationally in early post-emergence on maize, under conditions similar to those in which this study was carried out, and would lead to a decrease in the use of herbicide without negative consequences in terms of crop yield. At the same time they allowed to increase the biomass production as compared to no-treated area. The saving of herbicide amounted between 14 and 39.2 % for patch spraying as compared to a blanket application, allowing to save from 16 to 45 € ha -1 . The saving of herbicide is function of weed coverage and thus of the level of infestation over the field.

2.3 Pest management. Weeds control. Example 2

The objective of this study was to acquire GPS coordinates simultaneously with digital images of weeds in early-season cotton and to develop an automated routine to identify and map weed and crop densities for crop management. [11]

Video and coordinate data were simultaneously collected while traveling along the seedline of the crop at an average speed of 1.57 mph. GPS time was synchronized with the digital videotape time-code by filming GPS time on the receiver display at the beginning of each row.





The system demonstrates the technical feasibility of automated weedmapping. With a processing rate of 10 images per second, the potential for labor savings compared with conventional weed-mapping methods is significant. The technique could be combined with farming operations — including planting, cultivating or chemical applications (such as fertilization or insecticide sprays) — further reducing labor, fuel and equipment (such as tractor) costs. An automated, low-cost, weed mapping system would allow growers to track weeds throughout the season to provide feedback on the efficacy of weed management programs and in GPS yield map analysis.

3 Yield monitoring

(Slide 16-19 from document *LectureGIS.pptx*) [12]

Many growers have invested in yield monitor systems that have been standard equipment on combines for a number of years. Data from these systems can provide valuable information on areas of the field with significantly lower yield. This information, especially with data collected over a number of years with different weather conditions, can be used to address problem areas and improve yields. Yield monitor data is increasingly being used in precision agriculture to develop precision for fertilization, spraying and variable rate planting.

Importance for Water Quantity Management

Crop productivity is highly dependent upon soil moisture, often the most limiting yield factor in production. Crop production takes place on fields that are made up of many different soil types. Yield maps can give us insight into the potential benefits of investing in better drainage for heavy soils, or perhaps irrigation on lighter soils. Good data must be collected over a number of years, as yields on fields with variable soils will vary significantly in wet vs. dry years.

On irrigated crops, accurate data can be used to evaluate changes in yield due to variable irrigation rates across the field. Comparing yields in dry corners can be used to evaluate benefits of irrigation for that year.

Uniformity tests many times show significant differences in application rates across a pivot, and with accurate yield data, the impact of the different rates over the season can be determined. Accurate yield monitor data can also be used to show impact of variable nitrogen (N) rates with irrigation.

Importance in Crop Production

Accurate yield monitor data are especially important in helping to understand which factors are impacting corn yields. Accurate yield maps also help to identify areas of the fields where we may want to manage inputs such as N or seeding rates to help reach top potential yields on different soil types.

One of the most important inputs in corn production is N. Since N availability is highly dependent upon environmental loss (leaching, denitrification and volatilization) and mineralization of organic matter, correlation of yields to soil type given a season’s rainfall may help us to better manage timing and type of applications to maximize returns when managing inputs. On lighter soils, sulfur availability is playing an increasingly important role in maintaining productivity in corn, and economic response to fertilizer sulfur will most likely be highly related to soil texture and organic matter levels at any given location in the field.

To state it plainly, good pest management is poised to become much more complex over the next several years. It is likely to take multiple applications of herbicide, insecticide and stepped up scouting to provide the same level of crop protection we have become accustomed to. Accurate yield mapping allows growers to evaluate different hybrids, traits and pest control strategies on their farm relatively painlessly by planting or spraying strips in a field. The added effort can pay off big if you can find ways to more cost effectively manage pests or select high yielding varieties for your farm.

3.1 Processing Yield Maps

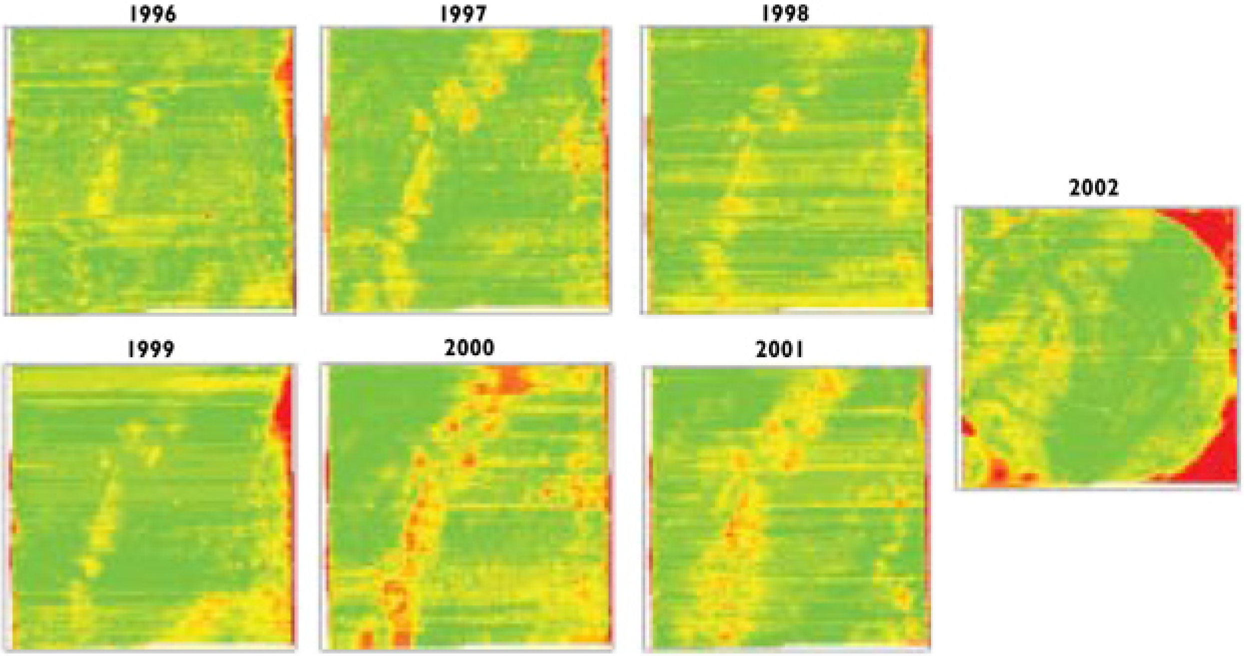
The yield calculated at each field location can be displayed on a map using a Geographic Information System (GIS) software package. The raw log file, however, contains points recorded during turns and the sensor measurements do not correspond to the exact harvest locations because grain flow through a combine is a delayed process (unless real-time correction is applied). To eliminate these obvious errors, the raw data is shifted to compensate for the combining delay, and the points corresponding to the header up position are removed. Settings for grain flow delay are combine- and sometimes even crop-specific, but typical values for grain crops range from about 10 to 12 seconds. [13]

Usually a few points at the beginning and at the end of a pass should be removed as well. These are referred to as start-and end-pass delays. Start-pass delays occur when the combine starts harvesting the crop, but grain flow has not stabilized because the elevator is gradually filling up. Similarly, end-pass delays occur when the combine moves out of the crop and grain flow gradually declines to zero when the elevator is completely emptied. Consult the manufacturer of your yield monitor for the most appropriate settings to use with your combine.

Shifting of raw data to correct for grain flow delay as well as deletion of points that represent header status up and start-and end-pass delays is the primary data filtering procedure built into software supplied with yield mapping systems.

Evaluating the temporal (year-to-year) variation of yield distribution within the field is an essential step in defining field areas with potentially high and low yields. Several approaches can be used to evaluate temporal effects on yield. One approach is to calculate the relative (normalized) yield for each point or grid cell. Normalized yield can be defined as the ratio of the actual yield to the field average:

When growing conditions in a field vary considerably, such as irrigated and dry land areas or different crops or varieties grown in different areas, normalization should be done separately for those areas, with the resulting relative yields recombined into one data file for the whole field. The following figure shows a relative yield history for a field with corn (soybean in the southern half in 2000) grown using furrow-irrigation (until 2001) and center-pivot irrigation (in 2002).

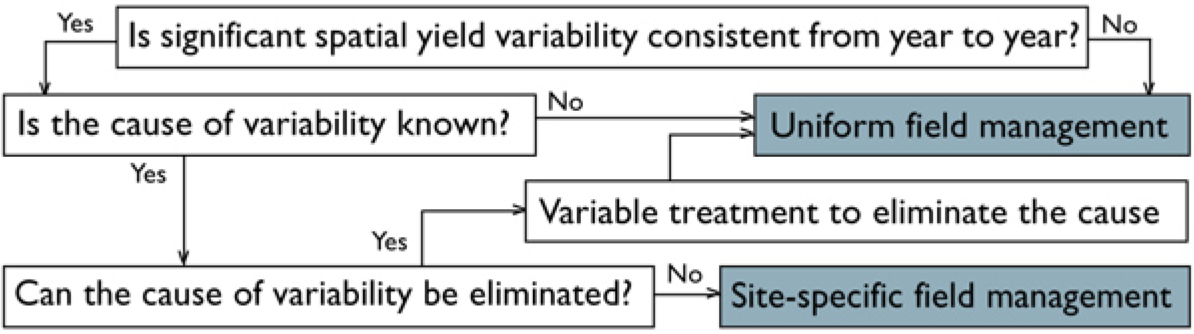


Maps of relative yield of corn and soybean grown during a seven-year period (red indicates low-yielding areas and green indicates higher than average yields).

3.2 Potential Applications

Yield maps represent the output of crop production. On one hand this information can be used to investigate the existence of spatially variable yield limiting factors. On the other hand, the yield history can be used to define spatially variable yield goals that may allow varying inputs according to expected field productivity.

The following flowchart illustrates the process one might follow in deciding whether to invest in site-specific crop management, based on analysis of yield maps. If yield variability across the field cannot be explained by any spatially inconsistent field property, uniform management may be appropriate. Site-specific management becomes a promising strategy if yield patterns are consistent from year to year and can be correlated to one or more field properties (e.g. nutrient supply, topography, past management, etc.).



If the causes for yield variation are known and can be eliminated permanently, the entire area could be brought to similar growing conditions and managed uniformly thereafter. This concept was one of the earliest philosophies behind precision agriculture, but is likely only feasible for certain field properties. For example, variable rate liming can be used to correct acidic areas in a field. In this case, the yield map is used only to investigate whether low soil pH is a yield-limiting factor, and the soil map is used to prescribe variable application rates. Another example would be localized deep soil tillage to alleviate compaction in selected field areas.

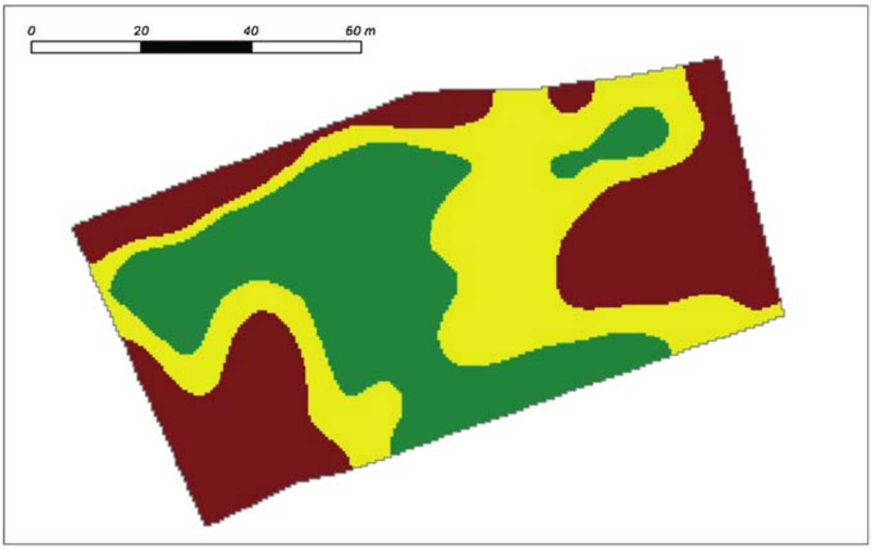
Most yield limiting factors cannot be modified permanently through single measures because of economic or practical constraints. Consequently, site-specific crop management may be used to appropriately account for the existing spatial variability in attainable yield and/or soil properties.

3.3 Yield monitoring. Grape yield mapping. Example

Regardless of the technique used to acquire the imaging, post-processing is still commonly based on calculation of the normalised difference vegetation index (NDVI). Based on sunlight reflectance in red (R) and near-infrared (NIR) wavelengths as per the equation (NIR-R)/(NIR + R), NDVI allows vineyard mapping as a function of a variable number of vigour classes (i.e. 2, 3, 5 or 10) within which vine performance is assumed to be similar. It thus represents a good indicator of the photosynthetically active biomass that is related to canopy size (vigour) and to vine health and stress status.

Gatti, M. et al. (2017) [14] aims to elucidate within-field variability in a vineyard located in north-west Italy through a standard NDVI approach, to provide agronomical ground-truthing on a 2-year basis (2012–2013) of the NDVI-derived vigour levels and to outline the best-fit strategy for optimal vineyard efficiency.

The trial was carried out in 2012 and 2013 in a commercial, non-irrigated vineyard of Vitis vinifera L. cv. Barbera – a standard material grafted to Kober 5BB – established in 2004 at Ziano Piacentino, Colli Piacentini wine district, Malvicini Paolo Estate (44°59 0 N, 9°22 0 E, 262 m a.s.l.), Italy.



Map of NDVI showing the high-vigour (HV, green), medium-vigour (MV, yellow) and low-vigour (LV, brown)

Satellite images with a 5 m pixel resolution taken at full canopy were successful at detecting vine vigour variability through NDVI assessment in a small Barbera vineyard. Ground-truthing performed on the LV, MV and HV classes thus identified showed close correlation between NDVI and vegetative, yield and grape composition parameters. The LV vines performed outstandingly in terms of remunerative yield (3.2 kg/vine corresponding to 13.3 t/ha) and full ripening while maintaining a considerable acidity level. Both MV and HV plots showed excessive vigour and cropping along with delayed ripening. Information derived from NDVI-based vigour mapping and proper ground-truthing paves the way for two decision-making options for sustainable crop management: (i) exploitation of natural variability through selective hand or mechanical harvesting in order to diversify final fenological products, or simply postponing MV and HV picking until their ripening delay is offset, and (ii) correction of natural variability through a variable rate approach to mineral and/or organic fertilisation in order to convert higher-vigour classes to LV.

4 Variable Rate

(Slide 21-26 from document *LectureGIS.pptx*) [14]

There are a number of questions that must be answered before establishing a site-specific crop management (SSCM) program. Many of these questions are economic, some are agronomic and environmental, and others are technology-related. This publication is intended to discuss variable-rate devices that are available, while providing an understanding of which technologies might best fit a cropping system and production management strategy.

Most farmers have practiced a form of variable-rate application (VRA) with a conventional sprayer. A conventional sprayer applies a chemical that is tank-mixed with a carrier (usually water) using spray nozzles and a pressure-regulating valve to provide a desired volumetric application of spray mix at a certain vehicle speed.

Any change in the boom pressure or vehicle speed from that of the calibration results in an application rate different from the planned rate. Applicators have used this to their advantage at times. For example, when observing an area of heavy weed infestation, the applicator can manually increase the pressure or reduce the speed to apply a higher (but somewhat unknown) rate of herbicide.

Variable-Rate Application Methods

One important technology-related question is: What methods of variable-rate application of fertilizer, lime, weed control, and seed are available? There are a variety of VRA technologies available that can be used with or without a GPS system. The two basic technologies for VRA are: map-based and sensor-based.

Map-based VRA adjusts the application rate based on an electronic map, also called a prescription map. Using the field position from a GPS receiver and a prescription map of desired rate, the concentration of input is changed as the applicator moves through the field.

Sensor-based VRA requires no map or positioning system. Sensors on the applicator measure soil properties or crop characteristics “on the go.” Based on this continuous stream of information, a control system calculates the input needs of the soil or plants and transfers the information to a controller, which delivers the input to the location measured by the sensor. Because map-based and sensor-based VRA have unique benefits and limitations, some SSCM systems have been developed to take advantage of the benefits of both methods.

Map-Based VRA

The map-based method uses maps of previously measured items and can be implemented using a number of different strategies. Crop producers and consultants have crafted strategies for varying inputs based on (1) soil type, (2) soil color and texture, (3) topography (high ground, low ground), (4) crop yield, (5) field scouting data, (5) remotely sensed images, and (6)
numerous other information sources that can be crop and location-specific.

Some strategies are based on a single information source while others involve a combination of sources. Regardless of the actual strategy, the user is ultimately in control of the application rate. These systems must have the ability to determine machine location within the field and relate the position to a desired application rate by “reading” the prescription map.

Sensor-Based VRA

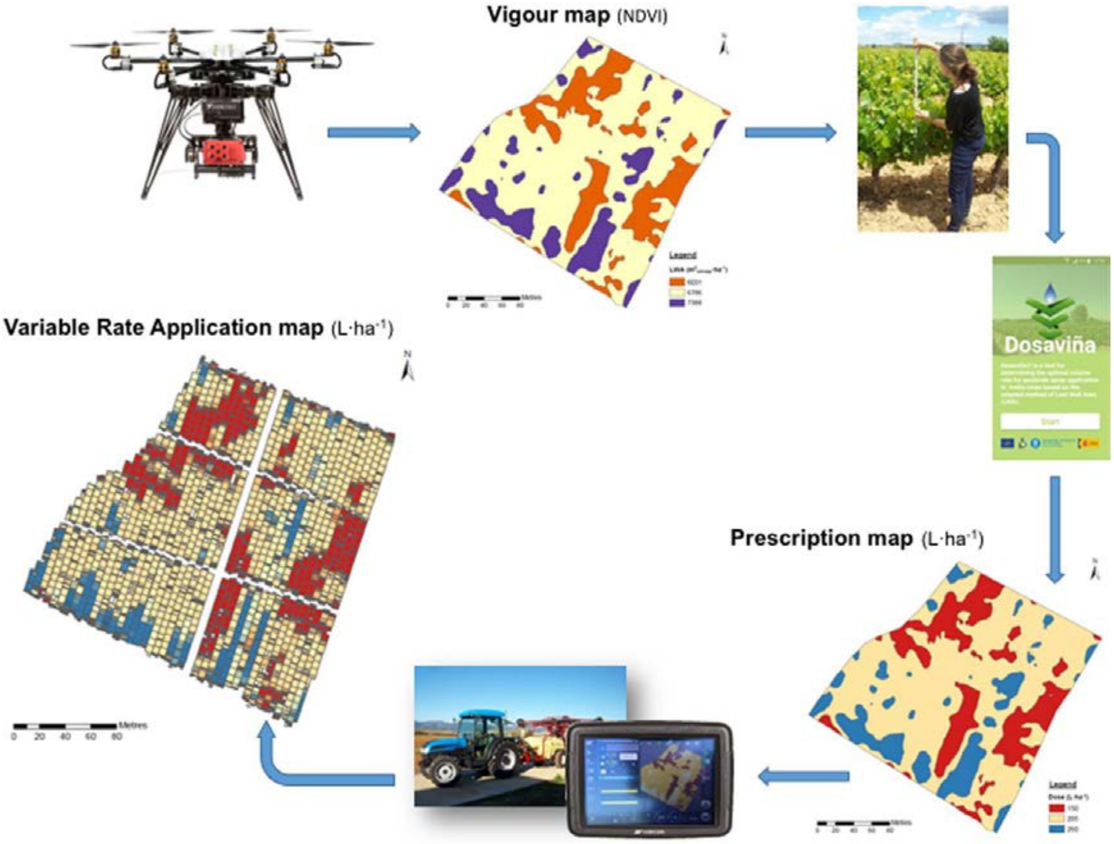
The sensor-based method provides the capability to vary the application rate of inputs with no prior mapping or data collection involved. Real-time sensors measure the desired properties — usually soil properties or crop characteristics — while on the go. Measurements made by such a system are then processed and used immediately to control a variable-rate applicator.

The sensor method doesn’t necessarily require the use of a positioning system, nor does it require extensive data analysis prior to making variable-rate applications. However, if the sensor data are recorded and georeferenced, the information can be used in future site-specific crop management exercises for creating a prescription map for other and future operations, as well as to provide an “as applied” application record for the grower

4.1 Variable Rate. Example

Javier Campos et al. (2019) [16] find a good correlation between data obtained from remote sensing technologies and canopy characteristics. The hypothesis is that NDVI is a good indicator of canopy vigor and consequently application volume can be varied by NDVI zones to maintain a roughly constant application coverage. The practical implications of that correlation will be shown in the form of a novel smart spray application device based on the principle of Variable Rate Application (VRA) adapted for vineyard plantations. The new developed technology will be able to follow a georeferenced prescription map obtained by combining the spatial canopy characterization together with the application of the modified method of LWA (Leaf Wall Area) generated by a newly developed Decision Support System (DSS) Dosaviña. The specific steps in this research were:

- To obtain a canopy map identifying the zones with clear differences in vigour
- To establish a prescription map (amount of liquid and pesticide) to be applied according to the previously defined canopy characteristic
- To develop a modified conventional orchard sprayer adapted for automatic site-specific management during spray application
- To evaluate the accuracy of the proposed method



Firstly, the orthophotomap created from the high-resolution imagery acquired with the drone, yielded a spatial resolution of 6.33 cm pixel −1 and was composed of the same five bands offered by the camera (R, G, B, RE, and NIR). The orthophotomap was radiometrically calibrated using four grayscale standards placed in the field at the time of light and visible in the image. Calibration curves were built with 22, 32, 44, and 51% gray scale reflectance standards for each of the spectral channels from the multispectral camera. The equations extracted from the calibration process were used to convert grayscale 12-bit digital numbers to reflectance values. The new reflectance images were then combined to calculate the normalized differential vegetation index (NDVI).

The results clearly show the positive effect of the variable rate application process. The total amount of liquid applied in the 5 ha parcel was reduced by 44.3% and 47.3% using the developed site-specific management sprayer, without and with US sensors, respectively.

The corresponding saving in terms of time was approximately 45 min for both cases, equivalent to circa 9 min ha −1 . Finally, the potential savings on active ingredient were 3.1 kg and 2.9 kg, with and without ultrasonic sensors, respectively. The obtained results can be directly linked with the objectives established in the European Directive for Sustainable Use of Pesticides (EU 2009)

5 Conclusion and Future challenges

(Slide 27 from document *LectureGIS.pptx*) [17]

GIS has still yet to be taken up in en masse in agricultural science yet there is massive potential for such areas as agricultural planning, attractive implications for the future of managing our crop production and increasing yields in line with other technology. Agricultural scientists are always looking at ways to best produce our crops, manage soils while respecting the environment and protect them from disease and pests. There is an ongoing challenge to cope with the changing climate and needs of today. GIS can play a vital part in tackling these challenges.

Use of GIS is fairly limited at present in Agricultural Science, but there are many acknowledged uses even where the tool is not actually being used in practice. There are many strategic advantages for potential future agriculture practice and policy and the industry is only just starting to notice them. Avoiding droughts, floods and insects by strategic planning can improve both yield and quality of a crop (2) and changing crops as soil changes can maintain maximum yield and protect the environment.

For the most part of human history, agricultural planning has largely been a system of guesswork. Even where a large set of data has been acquired for a particular piece of land, there are variable factors that we cannot account for and we go with the best fit. GIS can take the guesswork out of the crop planning management with effective collection of soil data and seasonality of topography in line with changing conditions. It allows for precision farming, permitting vineyards for example to maximize yield and quality (3).

Soil quality is never ubiquitous, even within a single field. If the field slops, drainage and water access can change drastically over just a few feet (because of drainage). Other factors that can affect quality is how much sunlight, shade or rain a certain area gets, the nearness of one side to a road (and therefore the potential pollution level, dust or fragments of artificial material such as rubber and metal) can all affect the quality of a crop (4).

Mapping is used to find archaeological features in our agricultural land and this has for many years been a successful tool in the heritage industry (5). However, the same types of data will be useful for agricultural science as underlying features can affect the quality and relative height of the crop produced. The same is true of underlying bedrock.

Identifying new areas to plant crops, either to make existing yields more efficient or simply to continue to provide increasing yields for our growing global population, is presently and will continue to be the biggest challenge for agricultural science. GIS is presently being used as a crowd sourcing project to manage food security and to reorganize crops in the third world (6) to ensure that maximum use is made from the fragile soils in some areas.

GIS is essential in mapping areas, especially food sources, that are vulnerable to natural disasters such as drought and flood. The World Food Program, the division of the United Nations concerned with food security, is one of the biggest users of GIS data for this purpose (7). They are involved in protecting food supplies by effectively building simple civil engineering projects such as damns, levies and irrigation to protect food supplies

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