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Spatial Analysis in Agriculture: An Overview of Precision Agriculture

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PRECISION agriculture is a spatial information technology applied to agriculture. Also it is known as site-specific farming that encompasses collecting and analyzing data for different locations within a field in a way that allows management decisions to vary in those diverse locations. Spatial information technologies include global positioning systems (GPS), geographical information systems (GIS), variable-rate technologies (VRT) and remote sensing (RS). Global positioning systems utilize a group of satellites used for accurately locating ground position. Geographical information systems encompass computer hardware and software with procedures for compiling, storing, retrieving, analyzing and displaying spatial data. They are designed to assist with planning and decision-making. Variable-rate technology is used for applying soil amendments at variable-rates within a field. Remote sensing involves the detection of energy reflected or emitted from an object with a sensor that is not in direct contact with the object. In sum, precision farming combines these technologies to help with decision making by providing information needed for crop and soil management in specific field locations.

In little more than a decade, precision agriculture has emerged from a concept to production-scale, multiple-task operations implemented on a field-by-field basis. Precision agriculture is a way to mange the heterogeneity within a field. It's a tool to handle the spatial and temporal variability and control the (local) processes in the field. An ensemble of collected information (yield maps, soil maps, multi-spectral satellite images, ...), management decisions and outputs (fertilizing, irrigation, drainage, sparing) can be used for different goals. The developed management strategy can result in a reducing of inputs, higher profitability, environmental protection and/or higher yields. Although implementation of precision agricultural technologies was initially rapid, it has slowed due to difficulty and confusion about how the full power of precision agriculture can be maximized and thus how the true value can be determined. Early users were primarily self-taught who shared an aptitude for electronic-based information technology and decision making. Adoption of precision agriculture technologies and methods has evolved as the general user profile has changed and as analysis demands have increased. The challenge for users of precision agriculture technology is to effectively measure, collect and analyze relevant variable and manageable factors to make efficient management decisions.

Reluctance towards implementation of precision agriculture seems to be based upon accessibility to well-trained and knowledgeable people, cost and availability to obtain quality education and training. The learning processes of precision agriculture technologies and methods are outlined as six sequential steps. These steps represent a process of increased learning and skill proficiency against which those individuals developing precision agriculture education can use to build and target their programs. The optimal value of information for precision agriculture will be best achieved by producers, agribusinesses and educators as they improve their skills in: 1) agronomic knowledge, 2) computer and information management and 3) understanding of precision agriculture as a system for increasing knowledge.

Precision agriculture education programs need to reflect these dynamics of change, but they should also be scientifically sound and responsive to the wide range of abilities and skills of individuals. To illuminate how precision agriculture educational programs can be improved and expanded, this paper addresses three questions:

1. What barriers to the adoption of precision agriculture are the results of inadequate or ineffective educational efforts?
2. Is there a natural learning process for precision agriculture technologies and methods? And if so, what is it?
3. What are the unique needs of the different precision agriculture players (*e.g.*, producers, agri-business and educators)?

Comprehensive Approach

Precision farming is a way to manage the heterogeneity within a field. Traditional agriculture considers a field as a homogeneous unit. Fields used to be smaller and more uniform, field boundaries were probably adapted to get uniform fields. As a result of mechanization, farmers are able to work bigger areas and fields became bigger and more variable. Because of the large areas of farms and fields, farmers (and agronomists) lost their feeling with the fields and are looking for tools to manage the local differences in fields. Nowadays, technology makes it possible to handle these differences and treat the fields in a local way.

Precision farming is a tool to handle the spatial and temporal variability and creates a framework to understand and control the (local) processes in the field. An ensemble of collected information (yield maps, soil maps, multi-spectral satellite images, ...), management decisions and outputs (fertilizing, drainage, spraying, ...) can be used for different goals. The developed management strategy can result in a reducing of inputs, higher profitability, environmental protection and/or higher yields (Casady & Massey, 2002).

What are the goals of precision agriculture?

Maximizing yield

The models for homogeneous fertilizing are based on uniform field properties. However, areas were the amount of nitrogen is not the growth limiting factor are overfertilized while others are underfertilized. Redistributing the same amount of nitrogen taking into account the maximum local yield potential can lead to a maximum yield for a lower or equal input level.

Minimizing input

When the plant growth limiting factors are known locally, it is possible to calculate the local needs to have a maximum potential yield. An example: weeds are mostly located as spots in the field. Knowing those spots in the yield and using a local treatment can greatly reduce the amount of herbicides used.

Maximizing financial advantage

Having the same yields while using less inputs will lead to a higher financial income. This implicates that the investments must have an acceptable level.

Minimizing the environmental impact

The homogeneous treatment almost always implies an overdose of inputs in adefinite field area. This overdose will not be taken up by the plants and will pollute nature, water, soil or air. By putting just what the crop needs, all inputs are taken up with minimal environmental impact (Naiqian *et al.*, 2000 and Casady & Massey, 2002).

Where does it starts?

Precision farming is a cycle that mostly starts at the harvest of a crop. Based on the yield map, the critical areas in the field can be discovered. Based on the soil properties, weather conditions and the yield map, the farmer takes his management decisions. The decides were to have what seed and fertilizer rate. By the end of the season, a new map is created and variability in time can be evaluated. Areas that have the same response (clusters) can be derived and the amount of soil samples can be reduced (Lui *et al.*, 2003) (Fig. 1).

How about precision farming today?

The farm area has to be big enough for precision agriculture to be profitable. Economical studies indicate that the farm needs at least 100 ha to have a profitable precision agriculture cycle. However, parts of the cycle can be very interesting. If the farmer has only a yield map it can be a very useful tool. Mostly farmers know there are problems in the field, but they can not put numbers on the effects of the problems. By calculating the critical yield to be profitable, it is possible to indicate the areas that are better not cultivated or where the farmer has to intervene (adding drainage, placing a fence or putting his field aside) (Casady & Massey, 2002).

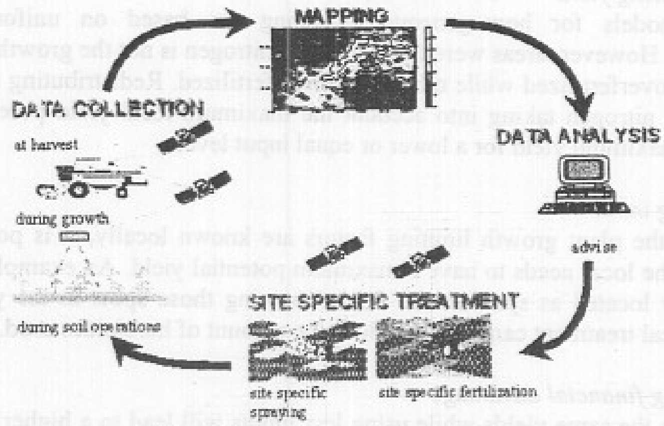

Fig. 1. Precision agriculture cycle.

A truly comprehensive approach to precision agriculture must cover all phases of production from planning to post harvest. Information, technology and management are combined into a production system that can increase production efficiency, improve product quality, allow more efficient chemical use, conserve energy and provide for soil and ground water protection (Lui *et al*., 2003).

Keys to Success

To be successful, comprehensive precision agriculture relies on three key elements:
* Information
* Technology
* Management

Information is perhaps the modern farmer's most valuable resource. Timely and accurate information is essential in all phases of production from planning through postharvest. Information available to the farmer includes crop characteristics, soil properties, fertility requirements, weed populations, insect populations, plant growth response, harvest data and post harvest processing data. The precision farmer must seek out and use the information available at each step in the system (Naiqian *et al*., 2000 and Casady & Massey, 2002).

Modern technology in agriculture is the second key to success. Technology is rapidly evolving and the farmer must keep up with the changes that may be of benefit in his or her operation. The personal computer is one example of such technology. The computer can help the farmer organize and manage data more effectively. Computer software, including spreadsheets, databases, geographic information systems (GIS) and other types of application software are readily available. The global positioning system (GPS) has given the farmer the means to locate position in the field to within a few feet. By tying position data in with the other field data mentioned earlier, the farmer can use the GIS capability to create maps of fields or farms. Sensors are available or under development that can monitor soil properties, crop condition, harvesting, or post harvest processing and give instant results or feedback which can be used to adjust or control the operation.

Management, the third key to success, combines the information obtained and the available technology into a comprehensive system. Without proper management, precision crop production would not be effective. Farmers must know how to interpret the information available, how to utilize the technology, and how to make sound production decisions.

Methods

To practice precision agriculture, growers must select and use the necessary equipment and technology. There are a lot of equipment choices available to the modern grower. Equipment users should carefully evaluate the capabilities and equipment before they purchase. For example, in chemical application, the goal is to deliver the material to the correct target at the proper rate. Errors in application rate should be kept as low as possible. By selecting equipment capable of high accuracy application, the grower has achieved the first step in implementing precision agriculture. The same concept is true in planting, tillage, harvesting and post harvest equipment decisions. Growers should not rush into a complete system until they have identified the elements that will benefit their farm (Mohamed *et al.*, 2002).

A natural learning process for precision agriculture

The knowledge and skill that people gain through precision agriculture are acquired through a natural, orderly learning process that has been experienced by producers, agribusinesses and researchers. Although individuals will not necessarily follow the learning process in the exact order presented here, the stages have been and will continue to remain somewhat sequential. Six learning steps involved in the adoption and application of precision agriculture along with supporting points and examples are presented below (Kitchen *et al.*, 2002)

Step 1: Learning and understanding the concept of spatial data management, including the importance and value of spatial data is fundamental. Opportunities for successful precision agricultural decisions are founded both in the variability that is present in a field and in the ability to accurately predict and influence those variable factors.

One should understand the concept of scale of variability. While thinking spatially is not totally new to agriculture, measuring and making decisions about how things vary in space is. Implications for the potential benefits and costs from each management decision include understanding the choices of relevant precision agricultural treatments for a location. This serves as a basic first step in the development of a precision agriculture management plan.

Realizing that maps contain information beyond visual perception helps users to understand how mapped data can be used in analysis and management decision making. Precision agriculture management involves much more than simply creating "pretty maps".

Mapped information will vary in its relative importance for improving the crop production system. Accuracy in sampling and data collection has significant implications for the inferences drawn from mapped data. Considerations of information accuracy, return to agronomic principles to determine the hierarchy of yield limiting factors and how these factors can be managed for successful crop production stand as the foundation of a precision agriculture data management.

Step 2: Learning the proper use of sensors makes it possible to obtain intensive sampling of quality information relatively inexpensively. Automated sensors and controllers can be used to collect information and vary inputs on-the-go. In many cases, the relative novelty of sensors and computer-controlled devices presents precision agriculture users not only with issues of how to manage spatial variability, but also with a Pandora's box of cables, sensors, and computers. Education and training address the development of skills and confidence needed in the operation of these sensors. Examples of the kinds of ensors commonly used in precision agriculture include:

* *Global positioning system (GPS)*

- The evolution of GPS represents the one primary key factor that has allowed precision agriculture technology to progress to its current state.
- The information provided through GPS ties together all relevant layers of information obtained for a field (Fig.2).

Fig. 2. Collecting soil samples using GPS.

** Yield monitoring systems*

- Yield monitors have given users of precision agriculture technology a baseline by which they can evaluate their management decisions.

- Yield monitors collect data on-the-go across a field to provide a spatial representation of yield performance (Fig. 3). However, to ensure quality data, a yield monitors must be installed properly and calibrated. This could increase harvest preparation and collection time, but it is a critical benchmark in the evaluation of precision agriculture management decisions.

Fig. 3. Yield harvest using GPS.

** Remote sensing data*

- The use of remotely-sensed images is still an emerging piece of precision technology. However, it offers a frontier of within-season crop production information critical to the adjustment of a plan.

- Challenges remain on how to interpret and manage remotely-sensed data within existing precision agricultural management programs. Inclusive with this challenge are issues associated with management of image data within a software package and availability of proper software.

** Variable-rate technology (VRT)*

Although initially tied with the variable application of fertilizer, VRT can be used in all facets of the management of the soil and crop (Fig. 4). Development of a "spatial prescription" along with using a sensor to apply it requires additional calibration and training to ensure a product is properly applied. All of the listed hardware technology, while not all inclusive, implies a need for additional educational efforts.

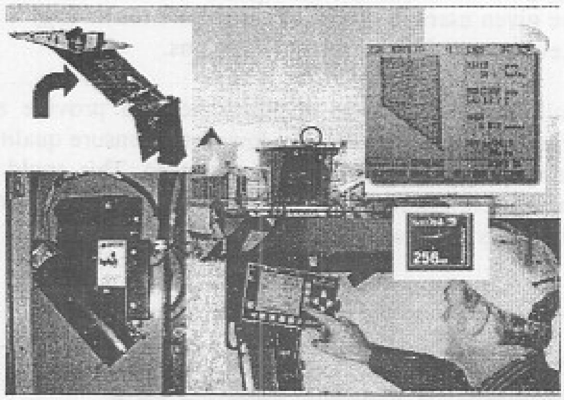

Fig. 4. Variable rate technology (VRT) using GIS/GPS.

Frustration in the learning process can be overwhelming, but time provides increased confidence and experience to obtain and apply information. This step in the learning process can be extensive, but given that data management lies at the heart of making informed decisions, this along with learning to use a computer may be one of the most important steps.

Step 3: Learning to use a computer and software is essential for mapping computerized maps. Large amounts of spatial information can be stored and summarized using Geographic Information System (GIS) software.

- GIS is the foundation of precision agricultural management from a decision-making perspective.
- GIS not only provides storage and display mechanism, but more importantly, offers an analysis and query ability that lies at the heart of making site-specific decisions. Within GIS, visual methods for cleaning data and performing statistical analysis can be routinely accomplished.
- Desktop mapping packages provide the ability to create, view and store spatial data with varying degrees of functionality, depending on the software. A GIS adds the ability to query and create new maps from old maps based on the question asked by the user. The ability to progress from raw data to colored maps, to analyzing and asking questions, to making management decisions requires comfort and experience with computer operation as well as file management.

Step 4: Improved crop production decisions are made through assessment of yield variation and narrowing the potential causes. Identification of relevant and manageable yield influencing factors stands as the key to precision agriculture management. Adding the spatial dimension to traditional whole-field decision making enhances agronomic problem solving. The value lies in identifying those results that are an effect of management as well as the results of environmental factors (*e.g.*, soil, weather, weeds, insects, etc...). Important items to consider include:

* Yield variation patterns point towards natural vs. management-induced variation.
* Analyzing yield maps using methods, such as:

- Visual association of yield maps to other maps (*e.g.*, soil, topography, fertility and remotely-sensed images).
- Simple mathematical analysis (*e.g.*, correlation, average, standard deviation, histograms and scatter plots).
- More complex mathematical analysis (*e.g.*, multiple regression, non-linear statistical methods and spatial modeling).

The ultimate goal would be learning how to conceptualize and refine a hierarchy of yield limiting factors for each field from which management implications and decisions are drawn on a more site-specific basis than on a traditional, whole-field approach.

Step 5: With relevant information collected, summarized and interpreted, one is ready to develop site-specific management (SSM) plans.

- The hierarchy of yield-limiting factors should lead one to prioritize management options.
- The final objective is to determine achievable goals and to invest in technology in order to help realize those goals, while recognizing that some results may not be instantaneous.
- Managers should not overlook that the value of SSM may increase by linking inputs (*e.g.*, variable-rate corn planting population and variable-rate nitrogen rates).

Step 6: Strategic sampling and on-farm trials constitute the last step optimizing management. The process and level of detail precision agriculture technology affords can make a manager more efficient in the decision-making process. Examples of precision agricultural methods may include:

- Use of within-season remotely sensed information to monitor crop progress and stress caused by biotic factors and subsequent spot treatment.
- Strip trials of seed variety and creating difference maps.
- Fertility response plots or strips.
- Tillage strips.
- Timing of planting and crop inputs,
- Profitability mapping.
- Pesticide stress (degree of phytotoxicity) monitoring.
- Pesticide effectiveness trials.

We concede that a description of the learning steps does not represent a fundamentally new evaluation of precision agriculture education. However, the steps do represent a process of increased learning and skill proficiency against which those individuals developing precision agriculture education can use to build and target their programs.

Assessment and management of variability

Assessing variability is the critical step in precision agriculture since it is clear that one cannot mange what one dose not knows. The processes and properties that regulate crop performance and yield vary in space and time. Adequately quantifying the variability of these processes and properties and determining when and where different combinations are responsible for the spatial and temporal variation in crop yield is challenge facing precision agriculture (Mulla, 1997). Techniques for assessing spatial variability (Geostatistics) are readily available (Trangmar *et al.*, 1985; Warrick *et al.*, 1986 and Isaales &Srivastava, 1989) and have been applied extensively in precision agriculture.

The interpolation of point samples technique is famous for assessing spatial variability. A network of points in some spatial arrangement is sampled and then interpolation to produce a spatial estimation (usually a kriging map) of the whole area using a range of statistical procedures. Ultimately, farmers must be able to delineate areas that will respond similarly to inputs that optimize crop performance. Maps form one basis for precision management; real-time management forms the other basis. Use of management maps is more common and these can be categorized as condition maps. Sensor data also need to be integrated with advances in software that will improve our understanding of the spatial and temporal variation in the properties and processes that regulate crop production. Condition maps are a critical component of precision agriculture and can be generated in four major ways: (i) surveys, (ii) interpolation of a network of point samples, (iii) high-resolution sensing, and (iv) modeling to estimate spatial patterns. All these methods are scale dependent and have limitations to their use in precision management. Once variation is adequately assessed, farmers must agronomic inputs to know conditions employing management recommendations that are site specific and use accurate variable rate technology (VRT) (Robert *et al.*, 1993; Robert *et al.*, 1996 and Robert, 1999).

Barriers to the adoption of precision agriculture: identifying opportunities for improved education

Producers, as the end-user of precision agriculture technologies and methods, will ultimately dictate the rate and extent to which precision agriculture is adopted. Research investigations and/or marketing strategies will fail in the end unless producers can realize value in such efforts, whether implicit or in absolute dollar terms. Thus, an understanding of the specific concerns that producers have about precision agriculture technology should provide insight into research, development, education and commerce opportunities. In 1998, producer focus group discussions yielded information to determine the barriers that prevented or inhibited increased adoption of precision agriculture (Wiebold *et al.*, 1998). Table 1 classifies the specific obstacles identified by these groups into six primary barrier categories. Are these barriers the result of inadequate or ineffective educational efforts? While educational programs should be integrated into all efforts to improve precision agriculture, some of the barriers found in this study clearly point to a problem of insufficient or ineffective education (italicized points in Table 1). These points suggest that producers want to know how to incorporate precision agriculture management into their operations. The reluctance towards implementation seems to be based upon accessibility to well-trained, knowledgeable people and the cost and availability to obtain quality education, training and products. The producer discussion groups revealed a wide range of different precision agriculture needs. For example, curriculum and teaching methods for precision agriculture education ought to be responsive to the changing needs of producers and agribusiness. As precision agriculture continues to mature, educational programming will need to be tailored to address the range of educational needs represented by both the beginner and advanced user. Over the last couple of years, beginning and advanced training/classes have begun to be offered at workshops, conferences and on college campuses. To promote adoption, the development of more narrowly specialized levels, ranging from novice to advanced, will be needed in future years to keep up with the increasing diversity in precision agriculture knowledge and skills.

In general, the outcome of the referenced discussion groups may reflect what producers think they want and not necessarily what they need. On the other hand, who other than producers has the intuition of whether precision agriculture will reasonably work? The new management complexities that precision agriculture technology adds to an operation require expanded skills and tools not previously taught or provided from an educational standpoint. An obligation exists to provide information and training from any relevant source in order to ensure that precision agriculture tools properly applied. Meanwhile, producers also shoulder the obligation to express their relevant needs and concerns so that these issues can be properly addressed from an educational standpoint.

Identifying the unique needs of precision agriculture players

Recommendations for improvements

Kitchen *et al.*(2002) and Mishra *et al.*(2003) suggest that there are three broad areas where improvements in precision agriculture can be made: 1) agronomic knowledge and skills, 2) computer and information management skills and 3) the recognition and development of precision agriculture as a management system for increasing knowledge. Within each of these dimensions, educational efforts should emphasize the specific needs of the significant players interested and/or potentially involved in precision agriculture: producers, agribusiness and educators.

TABLE 1. Results of producer focus groups examining the barriers that prevent or inhibit increased adoption of precision agriculture (PA) (Wiebold *et al.*, 1998).

Barrier Categories	Specific Obstacles*
Costs of technology adoption	* Equipment costs * *Time involved in learning how to use complicated equipment/ software* * Time consuming when time is already at a deficit (*e.g.*, harvesting) * Software packages are not compatible * Service providers unable to keep up with PA obligations * Obsolescence potential of hardware and software * *Producers and/or hired help without basic electronic equipment skills* * Issues associated with long-term investing for rented vs. owned land
Training programs and consultation resources	* *Training deficiency for producers and service providers to use technologies correctly, especially software and data and analysis* * *Gaps between getting information and finding answers* * Lack of confidence that current PA tools give the most relevant information * *Lack of technical infrastructure to help get through the PA learning curve* * *Lack of easy-access troubleshooting help* * *Lack of local experts*
Data quality control	* *Difficulty in maintaining quality data* * *Difficulty in storing and retrieving data with different formats* * Sensors that are unreliable or inaccurate * *Methods to analyze yield data to help understand yield limiting factors* * Better agronomic data for inputs (*e.g.*, seed) explaining responsiveness under different environmental stresses
Consumer guide for precision agriculture	* *Information providing comparative advantages/disadvantages of PA equipment, techniques and software*
Environmental aspects of precision agriculture	* Documented environmental benefits without compromising yield * Mechanism for demonstrating good stewardship with PA management * Development of linkage between PA and soil health
Need for new technology development	* New sensors and methods for detecting and treating biotic factors such as weeds and diseases * Influence of soil moisture and applications of variable irrigation * Crop varieties responsive within a PA system * Improved data storage devices * Development of remote sensing equipment * Standardization of equipment and data formatting * *Basic agronomic research on the relationships between yield and soil*

* Italicized points are mostly the result of inadequate or ineffective educational efforts.

Integrating precision agriculture into a system

Producers: The initial concept that precision agriculture means variable-rate fertilizer application is slowly being dissolved. Producers who have yield-mapped their fields for several years are examining the yield variability and they are asking the basic questions necessary to understand its causes. Fertility issues are now viewed as just a small part of the variability story. Producers are beginning to use the tools of precision agriculture to conduct on-farm field trials of different management options. Precision agriculture represents a way of learning through collecting, integrating and interpreting spatial and temporal in formation. It is not a component of management nor the sum of different components of management (Kitchen *et al.*, 2002).

Need: Producers of precision agriculture embrace the ideas and technologies of commensurate with what their time and resources will allow. We advocate that producers recognize precision agriculture as a change in their management perspective and as a way to learn. If a producer seeks only immediate and guaranteed returns, that producer may be disappointed by precision agriculture technology.

Agribusiness: It is much easier to market a single component of management that can be directly evaluated for its increased profit potential rather than to show how a product or service will assist a producer in the precision agriculture learning process. Agribusiness representatives will need tools and training to assist efforts at broadening their approach to present a whole farm solution (Kitchen *et al.*, 2002).

Need: There are many opportunities for different agribusinesses, sometimes in collaboration with public research institutions, in work together to develop products that help pull information together for greater understanding of the overall crop production system.

Educators: Teaching a system requires an ability to discuss its parts; but if we only discuss the parts and the various discussions make no concerted effort to each precision agriculture as a system, then we will fail. Precision agriculture works toward a multi-disciplinary approach of teaching that may be new to some educators. Additional effort may be necessary to involve and coordinate educators from other disciplines (Kitchen *et al.*, 2002).

Need: Educators of precision agriculture need to organize and promote education and research programs in an interdisciplinary and cooperative manner, which historically has not been a strength of academicians. Precision agriculture represents an opportunity to meld the agricultural disciplines. For public-funded education and research, the recognition and reward of interdisciplinary, team-oriented activities have often fallen short of the level of acclaim given to narrowly defined studies. The reward and promotion structure for public and private-sponsored educators should encourage, not discourage, interdisciplinary programs.

Evaluation of precision agriculture

An evaluation of precision agriculture is also required. Three important evaluation issues surrounding precision agriculture remain unresolved: economics, environment, and technology transfer. The economic evaluation focuses on whether the documented agronomic benefits - translated into value through market mechanisms - exceed the technological and service costs. Environmental evaluation focuses on whether precision agriculture can improve soil, water, and the general ecological sustainability of the agro ecosystem. Finally, and perhaps most important, is the question of whether this bundle of enabling technological and agronomic principles will work on individual farms. Being technologically feasible and at least economically neutral are necessary conditions but, as will be shown, may not be sufficient conditions for transfer to farms (Fixen, 1988; Enget & Gaultney, 1990; Verhagen *et al.*, 1995 and Lui *et al.*, 2003).

Action strategy of agricultural research system in Egypt

Since 1960, food production in Egypt has failed to keep pace with consumption. A number of factors have contributed to increasing this gap, including:

1. A low level of investment in agricultural research;
2. Slow growth in agricultural products;
3. Rapid population growth and a large increase in per capita food consumption.

The gap between food production and consumption will continue to widen unless there are substantial changes.

A significant amount of research into food and agricultural production is being conducted at national level throughout the country and financed from many resources. Much of this research work is part of a carefully planned and well coordinated effort reflecting national goals and needs. The organization chart of Egyptian research has various components:

- The Agricultural Research Centre (ARC) is the primary agency responsible for technology generation in the Ministry of Agriculture and Land Reclamation (MALR).
- The Desert Research Centre (DRC) is also under MALR, with five research stations, and is responsible for conducting research relevant to rainfed areas.
- The Water Research Centre (WRC) is part of the Ministry of the Public Work and Water Resources (MPWWR) and has 11 institutes and a training centre. It is responsible for conducting research on water resources and irrigation and drainage related to agriculture.
- The National Academy of Scientific Research and Technology and the National Research Centre (NRC) are also involved in agricultural research through their irrigation, food, and agriculture division. They belong to the Ministry of Scientific Research.

- The universities under the Ministry of Education.
- The National Centre for Radioactive Research (Ministry of Electricity and Energy)
- The private sector, which is increasingly involved in agricultural research, particularly in the area of seed production, tissue culture and micro-propagation and agrochemicals.

Future challenges of precision farming in Egypt

Precision farming as a system approach based on detailed site-specific information to manage farm operations according the spatial and temporal variability of growing conditions within a field for sustainable profitability is a relatively young field of agricultural research that emerged in the last decade. To adopt such a technology in Egypt, a multidisciplinary effort among several stakeholders, including government ministries and farmers, has to be coordinated.

Education comes as a first step aiming at providing the country with well qualified graduates in this field. Universities should offer specific courses on detailed information and concepts of precision farming which examine a wide range of subject areas including agronomy, crop physiology, genetics and plant breeding, soil and water sciences, entomology, meteorology, agricultural engineering, agricultural extension, weed science, ecology, spatial information sciences, agribusiness and economics.

The enhancement of the capabilities and the skills of the graduates can be done through the applied research conducted by specialized research institutes such as agriculture research center (ARC), national authority of remote sensing (NARSS),desert research center (DRC), national research center (NRC), and national water research center (NWRC). The research programs of these centers address, among others, issues from a farm system approach perspective where the whole farm is viewed as a system and the precision farming new technology can be applied. The results obtained from the applied research can be implemented in a large scale in farmers' fields by the Executive Authority for land Improvement Project (EALIP). The gained information and technologies can be extended to a larger group of farmers through well trained extension agents who has the ability to transfer the new technology to different farmer communities.

The new precision farming technology could be introduced, at the beginning, to the investors who can afford applying such a technology in their farms. Also, it could be applied in the national agriculture projects, *i.e.* Toshka, El-Salam project, and East of Owainat. The proposed approach will allow for better technology adoption, provide the feedback for technology refinement, identify constrains that need to be tackled by researcher, understand the social environment of farmers, and provide the information for policy makers to modify certain policy issues when needed.

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التحليل الفراغى فى الزراعة: الزراعة الدقيقة

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الزراعة الدقيقة هى تكنولوجيا معلومات الفراغ التى تطبق فى طرق الزراعة وهى عبارة عن تجميع وتحليل البيانات لمواقع مكانية مختلفة لحقول الدراسة وذلك لإتخاذ قرارات الإدارة المزرعية المثلى.

تكنولوجيا معلومات الفراغ تحتوى على نظام تحديد المواقع ونظم المعلومات الجغرافية وتكنولوجيا معدل الإضافة والإستشعار عن بعد. ويفيد نظام تحديد المواقع عن طريقة إتصاله بمجموعة من الأقمار الصناعية لتحديد المواقع الأرضية بدقة. ونظم المعلومات الجغرافية عبارة عن حفظ وإسترجاع وتحليل وعرض للبيانات الفراغية. ويتم تصميم ذلك مساعدة للتخطيط وصنع القرار المثالى وتكنولوجيا معدل الإضافة يستخدم لإضافة محسنات التربة بمعدلات مثلى داخل الحقل والإستشعار عن بعد يفيد فى ملاحظة إنعكاس الإشعاع من سطح التربة وذلك عن طريق الأقطاب الحساسة والتى تفيد فى تحديد الإضافات المثلى من الأسمدة والمياه والمبيدات والزراعة الدقيقة تتكون من حزمة تكنولوجية لمساعدة صناعى القرار بإستخدام المعلومات المتاحة لإدارة التربة والمحصول فى الإدارة المزرعية.

الزراعة الدقيقة هى دورة تبدأ فى حصاد المحصول وإستناداً إلى خريطة الأغلال يمكن تحديد المناطق الحرجة (ضعيفة الإغلال) بالحقل. وإستناداً إلى خصائص التربة والأحوال المناخية وكذا خريطة الإغلال تتحدد قرارات المزارع من حيث معدل توزيع التقاوى والأسمدة والمبيدات والرى. وبنهاية الموسم يمكن الحصول على خريطة جديدة ويتم تقييم التباين للتوزيعات المستقبلية وهكذا يمكن تحديد إستجابة المناطق طبقاً للإختلافات على شكل مجموعات عنقودية وكذا خفض عينات التربة التى تنقص مع مرور الوقت.

التردد فى تنفيذ الزراعة الدقيقة يرجع لأهمية إجراء الدورات التدريبية المتعددة ذات التكاليف المرتفعة وعمليات التعليم للزراعة الدقيقة هى عبارة عن حزمة تكنولوجية وطرق تتلخص فى ٦ خطوات وهذه الخطوات تتمثل فى زيادة المعلومات والمهارات بإستخدام تكنولوجيا المعلومات فى الزراعة. وقد أوضح إستخدام الحزمة التكنولوجية المعلوماتية التباين الحقلى للمحصول مما يترتب عليه وجود فجوة حقيقية بين مانحصل عليه ومايمكن الحصول عليه من نفس المساحة الأرضية ومع ذلك فايجاد مقياس للإختلافات المكانية يؤدى إلى تحقيق إدارة مزرعية مثلى يكون لديها فهم لأسباب هذه الإختلافات.

ويحتاج الباحثين إلى التدريب على مجموعة الحزم التكنولوجية المعلوماتية للوصول إلى نمط أمثل للإدارة الحقلية والذى من شأنه تحقيق أفضل إنتاجية وربحية وتحقيق مفهوم الزراعة المستدامة.