BENTUK TUGAS

MATA KULIAH : **Pertanian Berlanjut**
WAKTU : Minggu ke 5
SEMESTER : Ganjil **sks 6**

TUJUAN TUGAS :
Mahasiswa mampu memahami manfaat GIS untuk mendukung penerapan pertanian presisi dalam sistem pertanian Berlanjut.

URAIAN TUGAS :

a. Obyek garapan :**Mensintesis penerapan presisi pertanian dalam sistem pertanian berlanjut.**

b. **batasan-batasan dan yang harus dikerjakan**:

Apa itu Pertanian Presisi?

Pertanian presisi adalah upaya untuk menggunakan teknologi baru dalam meningkatkan hasil panen dan profitabilitas sambil menurunkan tingkat input tradisional yang diperlukan untuk menanam tanaman (tanah, air, pupuk, herbisida dan insektisida). Dengan kata lain, petani yang menggunakan pertanian presisi menggunakan lebih sedikit input untuk hasil yang lebih banyak. Perangkat GPS pada traktor, misalnya, memungkinkan petani menanam tanaman dengan pola yang lebih efisien dan melanjutkan dari titik A ke titik B dengan lebih presisi, menghemat waktu dan bahan bakar. Lahan dapat diratakan dengan laser, yang berarti air dapat diaplikasikan lebih efisien dan dengan lebih sedikit limbah pertanian yang mengalir ke gorund water dan sistem sungai. Hasilnya dapat menjadi keuntungan bagi petani dan memiliki potensi besar untuk membuat pertanian lebih berkelanjutan dan meningkatkan ketersediaan pangan.

Big Data untuk keputusan bertani

Salah satu bidang yang berkembang dari pertanian presisi melibatkan pemantauan dan analisis data yang terkait dengan kondisi cuaca, tanah, hama atau kekeringan dari lahan sistem pertanian tertentu, atau bahkan disetiap individu tanaman untuk membuat keputusan pertanian yang tepat dan dapat diprediksi dampaknya. Mengumpulkan dan mentransmisikan data lapangan menjadi tantangan saat ini dalam sistem pertanian, tetapi para inovator telah mencarikan solusi dari permaslahan ini.

Yang harus anda lakukan:

1. Untuk itu masing masing mahasiswa pelajari bacaan terlampir:

Srinivasan, A. 2016.. Relevance of Precision Farming Technologies to Sustainable Agriculture in Asia and the Pacific

Bongiovanni. R and J. Lowenberg-Deboer. 2004. Precision Agriculture and Sustainability. Kluwer Academic Publishers. Manufactured in The Netherlands.

2. Tetapkan kelompok kerja (anggota kelompok 3-4 orang), setiap kelompok melakukan observasi lapangan di bentang lahan pertanian, dalam skala mata memandang lakukan: Pengenalan dan Deskripsikan Karakteristik utama sistem pertanian yang berjalan saat ini dalam skala Lanskap.
3. Buat rekomendasi penerapan dan pemanfaatan GIS untuk mendukung implementasi pertanian berlanjut yang terinspirasi dari bahan kuliah dan bahan bacaan terlampir.
4. Di bentang lahan pertanian di lokoasi yang saudara observasi buat rekomendasi teknologi untuk penerapan pertanian presisi.

c. **Metodologi/ cara pengerjaan, acuan yang digunakan** :

Untuk melakukan studi kasus ini dilakukan melalui observasi lapangan. Kegiatan ini dilakukan secara berkelompok (3-4 mahasiswa yang mengambil matakuliah Petanian Berlanjut dan dikumpulkan hasil tugas ini pada satu minggu setelah penugasan ini, kepada dosen yang memberi tugas. Hasil kasus ini ditulis dengan bagian tulisan sebagai berikut: (1) halaman Judul tulisan dan penulisnya, (2) Bab 1: Latar belakang kasus, (3) Bab 2: Karakteristik dan Tantangan Pengembangan Presisi Pertanian dalam sistem pertanian berlanjut didukung dengan foto lapangan, (4) Bab 3: rekomendasi penerapan dan pemanfaatan GIS untuk mendukung implementasi pertanian berlanjut, dan (5) Bab 4: rekomendasi teknologi untuk penerapan pertanian presisi (6) Bab 5: Kesimpulan dan saran.

d. **Kriteria luaran tugas yang dihasilkan/ dikerjakan**:

Tugas ini disajikan secara tertulis dalam paper 20 halaman termasuk skema, tabel dan gambar, dengan ukuran kertas A4, diketik dengan type Arial 11 satu spasi.

KRITERIA PENILAIAN :

GRADE	SKOR	INDIKATOR KINERJA
Sangat Kurang	<45	Tidak mengumpulkan tugas
Kurang	>45-50	Tidak ada ide yang jelas untuk menyelesaikan masalah
Antara Cukup dan Kurang	>50–55	Ada ide yang dikemukakan, namun kurang sesuai dengan uraian tugas
Cukup	>50-60	Ide yang dikemukakan jelas dan sesuai, namun kurang inovatif

Antara Baik dan Cukup	>60– 70	Ide yang dikemukakan jelas, mampu menyelesaikan tantangan, inovatif, cakupan tidak terlalu luas dan kurang dijelaskan dengan baik
Baik	>70- 75	Ide yang dikemukakan jelas, mampu menyelesaikan tantangan, inovatif, cakupan tidak terlalu luas,namun dijelaskan dengan baik
Antara Sangat Baik dan Baik	>75- 80	Ide jelas, inovatif, dan mampu mengindentifikasi fakta lapangan dengan cakupan luas dan dijelaskan dengan baik serta mengikuti aturan tugas dengan tertib
Sangat Baik	>80	Ide jelas, inovatif, dan mampu mengindentifikasi fakta lapangan dengan cakupan luas dan dijelaskan dengan sangat baik serta mengikuti aturan tugas dengan tertib

Relevance of Precision Farming Technologies to Sustainable Agriculture in Asia and the Pacific

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Abstract

Deteriorating environmental quality, declining input response of major crops, and a widening gap between the potential and realized farm yields are main points of concern in current Asian agriculture. Adoption of precision farming through practices such as optimal application of inputs depending on spatial and temporal variability of crop yields and soil properties is increasingly recognized as a valuable approach to sustain yields and improve environmental quality. Because of wide diversity in crops and cropping systems, farm sizes and socio-economic conditions, Asian farming systems present both opportunities and obstacles for adoption of precision farming. The conditions in which precision technologies can be most rewarding and offer the greatest environmental benefits are highlighted, and the implications for adoption of precision farming in Asia are examined. A few approaches for implementing precision farming technologies in the Asian context are presented. The role of international organizations, governments, farmers' organizations and the private sector in implementation of these technologies is discussed.

Introduction

It is well known that sustainable agricultural development can happen only if the natural resource base upon which it depends is prudently managed. However, in sole pursuit of high productivity especially during the past 3-4 decades, a critical linkage between agriculture and the environment has been neglected resulting in agro-ecosystems with little resilience. This is especially so in Asia and the Pacific region, which accounts for more than 70% of the global agricultural population but only 30% of the world's farmland. Yield increases in this region have been achieved at considerable expense to its resource base and largely by means of excessive and indiscriminate use of external inputs: irrigation, seeds, fertilizer, pesticides, etc. High rates of aquifer depletion, pest and disease incidence, environmental pollution, soil erosion, and reduced biodiversity are, therefore, rampant. For instance, soil erosion in this region due to water and wind exceeds the natural soil formation by 30-40 fold (FAO, 1993). The problem of water quality deterioration is also serious. Pollution of drinking water in tobacco and rice ecosystems of Malaysia (Ahmad et al., 1996) and of groundwater near vegetable fields in Japan (Nishio, 1998) are just two examples. The effects of pesticide use on deteriorating farmers' health and enhanced pest resistance are also well documented.

Even intensively managed cropping systems in Asia seem to be unsustainable as productivity levels have reached a plateau or declined with a decreasing response to farm inputs and a widening gap between the potential and realized yields. Mounting populations, improving diets due to economic development, and increasing urbanization are expected to further enhance demand for more and superior quality food in this region. A better upkeep of key functions of ecosystems through adoption of environment-friendly technologies and holistic management of farm resources is, therefore, essential for agricultural sustainability. Modern strategies of management such as precision farming offer new opportunities for Asian farmers to optimize yields and profits and reduce pressure on natural resources, thereby leading to total quality management. Such strategies are based upon blending the best of farmer's local field knowledge with developments in geographic information systems (GIS), global positioning systems (GPS), remote sensing and the Internet.

Precision Farming and Agricultural Sustainability

Precision farming (PF) -- *also known as prescription farming, variable rate technology (VRT) and site specific agriculture* -- is considered the agricultural system of the 21st century, as it symbolizes a better balance between reliance on traditional knowledge and information- and management-intensive technologies. It is a holistic farm management strategy where farmers can adjust input use and cultivation methods -- including seed, fertilizer, pesticide, and water application, variety selection, planting, tillage, harvesting -- to match varying soil, crop and other field characteristics. PF differs from conventional farming that is based on uniform treatments across a field. It involves mapping and analyzing field variability, and linking spatial relationships to management actions, thereby allowing farmers to look at their farms, crops and practices from an entirely new perspective. PF thus provides a framework of information with which farmers can make both production and management decisions.

PF promises to revolutionize farm management as it offers a variety of potential benefits in profitability, productivity, sustainability, crop quality, environmental protection, on-farm quality of life, food safety, and rural economic development (Robert, 1999). Studies in USA, Canada, Europe and Australia have shown that PF permits reductions in input application rates without sacrificing crop yields. Refinement and wider application of PF technologies in Asia can result in lower production costs, higher productivity and environmental benefits, and better stewardship of natural resources. For example, site-specific application of pesticides in cotton and of fertilizers in plantations of oil palm, rubber, coffee and tea in Asia can greatly reduce production costs and decrease environmental loading of chemicals.

When judiciously implemented, farmers can benefit from PF technologies in many ways. In the short term, the diagnostic and database-building benefits will be enormous. Growers can forecast and alleviate problems such as water stress, soil compaction, diseases, and pests more effectively. Database-building benefits will be in the form of accurate farm document keeping for effective management of inputs, property, machinery and labor, and efficient monitoring of environmental quality through recording the amounts and location of input applications. In the long term, farmers can optimize agronomy through finding locations that produce maximum profit margins. PF technologies also increase opportunities for skilled employment in farming, and provide new tools for evaluating multifunctional character (including non-market functions) of agriculture and land.

Technology Components

PF has three requirements: 1. Ability to identify each field location, 2. Ability to capture, interpret and analyze agronomic data at an appropriate scale and frequency, and 3. Ability to adjust input use and farming practices to maximize benefits from each field location. A suite of technologies such as GPS, GIS, remote sensing, VRT, on-the-go sensors, grid sampling, monitors, and precision irrigation is used to fulfil these requirements. Various configurations of these technologies are suitable for different PF operations. Communication technologies such as the Internet are valuable for efficient delivery of PF services and products.

- **GPS** -- currently a constellation of 27 satellites developed by the US Department of Defence -- provides geospatial accuracy to farm practices and enables farmers to identify characteristics of each field site (where soil samples or pest data are collected). A minimum of four satellites is required to get good positional information. If a GPS receiver is used along with a ground reference station (Differential GPS), any location on earth can be identified to within one square meter. Sub-meter horizontal accuracy is now considered adequate for most PF applications. A crop scout can use GPS to map a field's insect or weed infestations and illustrate their locations with specific details. Likewise, kinematic GPS can be used for rapid development of accurate topographic maps.
- **GIS** is a computerized data storage and retrieval system, which can be used to manage and analyze spatial data relating crop productivity and agronomic factors. It can integrate all types of information and interface with other decision support tools. GIS can display analyzed information in maps that allow (a) better understanding of interactions among yield, fertility, pests, weeds and other factors, and (b) decision-making based on such spatial relationships. Many types of GIS software with varying functionality and price are now available. A comprehensive farm GIS contains base maps such as topography, soil type, N, P, K and other nutrient levels, soil moisture, pH, etc. Data on crop rotations, tillage, nutrient and pesticide applications, yields, etc. can also be stored. GIS is useful to create fertility, weed and pest intensity maps, which can then be used for making maps that show recommended application rates of nutrients or pesticides.
- Recently, **remotely sensed imagery** using low-flying aircraft or satellites has become a major source of information on spatial variability in fields caused by natural and cultural factors. Commercial satellites to be launched in future are expected to have ideal specifications for PF such as 3-day repeat coverage, 1 to 4 meter spatial resolution and image delivery to users within 15 minutes after acquisition. Remotely sensed images can show all fields in a village or block and spot problems sooner than ground inspections, thereby allowing remedial treatments to be taken up before the stress spreads to other parts of the field. In a

field survey, GPS can be used to pinpoint the stressed area for a detailed examination. Crop vigor changes can also be determined using images acquired at different times during a season. Such data, when combined with data from previous years, can be useful in predicting crop yields.

- **VRT**, the most advanced component of PF technologies, provides "on-the-fly" delivery of field inputs. A GPS receiver is mounted on a truck so that a field location can easily be recognized. An in-vehicle computer, which contains the input recommendation maps, controls the distribution valves to provide a suitable input mix by comparing to the positional information received from the GPS receiver. Current commercial VRT systems are either map-based or sensor-based (NRC, 1997). The map-based VRT systems require a GPS/DGPS georeferenced location and a command unit that stores a plan of the desired application rates for each field location. The sensor-based VRT systems do not require a georeferenced location but include a dynamic control unit, which specifies application through real time analysis of soil and/or crop sensor measurements for each field location. New VRT systems like the manure applicator being developed at Purdue University may soon enable precise application of manure in cropping systems.
- **Sensors:** Electronic crop and soil sensors that detect grain moisture levels, protein, water stress, disease or weed infestations, soil moisture, soil nitrogen, CEC, topsoil depth, etc. have been developed. A grain moisture sensor can help in optimizing harvest operations and storage and/or drying requirements. Sensors to detect soil quality "on-the-fly" and new machine controls that guide field equipment and can vary the rate, mix, and location of seeds, nutrients, water or chemical sprays are in development. Microprocessors and microprocessor-based control systems are especially useful in PF. For example, in a combine yield-monitoring system, microprocessors collect and store information from the GPS receiver and the grain moisture sensor. On VRT equipment, microprocessors obtain positional information from the GPS receiver, compare that data with the computer's map of the recommended application, and signal the applicator's control system to distribute the precise amount of inputs at that position.

New tools incorporating the above technologies are under development. For instance, a voice recognition system, which enables data collection with simple, easy-to remember voice commands regarding weed or insect problems, crop lodging, and other farm operations, is being developed at Purdue University (Dux et al., 1997). This data can be georeferenced using the GPS. The developments in the private sector are also worth noting. John Deere Company in the USA, for example, is creating an information infrastructure that can help in monitoring the performance of customer machines by computer, via satellite. With such infrastructure, a dealer or technician can inform the farmer of a machine's problems, and send a service truck immediately.

Relevance of PF Technologies to Asian Conditions

PF technologies have been developed in countries where farm socio-economic conditions are much different than in Asia. A question may therefore arise on their relevance to Asia, where a vast majority of population is subsistence-based, and strategies and perception of risk by farmers are totally different. It must be noted, however, that even under subsistence farming, several decisions (application rates of seeds, fertilizers and other inputs) have to be made for optimizing yields and income. As PF technologies assist farmers in improved decision making, and have the potential to reduce or remove the effects of limiting factors on the farm, a convincing case can be made on their suitability to Asian conditions.

PF technologies may be relatively new to Asia, but the concept of precision management is not. Asian farmers have long known that soil conditions, fertility, moisture, etc. vary widely across a single field and that various parts within fields responded to different types of inputs, and cultural practices. The small size of their farms often permitted such an effective monitoring of spatial and temporal yield variation and variable application of inputs mainly by manual means. Ever since the introduction of Green Revolution technologies in 1960s, however, Asian farmers treated all fields in a region uniformly leading to application of inputs in areas not needing them or where the crops cannot make full use of them. The micro-spatial scale has been neglected in favor of the regional and national scales. For example, fertilizer guidelines by agricultural experimental stations in Asia were primarily developed on a regional scale by considering the mean fertility of many fields. In addition, huge subsidies on fertilizers and pesticides, and labor shortage in some areas forced farmers to use the same application rates across the entire field. Ignorance of input-response functions also led to excessive use. The Asian farmer on average uses 127 kg NPK ha^{-1} against 78 kg ha^{-1} in the rest of the world (FAO, 1993). In China, for example, fertilizer use increased from 90 kg ha^{-1} in 1978 to 300 kg ha^{-1} in 1994. Pesticide recommendations are also regional and are based on a few random observations of pest density. Because of low quality of agrochemicals often due to adulteration and increased pest resistance, indiscriminate application is now common, especially in high value crops. Hefty subsidies on electricity for pumping water in some countries have led to over-exploitation of groundwater and misuse on farms leading to waterlogging and salinity. Application of PF technologies can help in reversing this trend.

Improving farm input use efficiency is also important from a macro-economic point of view. Many Asian governments are now reducing input subsidies to lessen their fiscal deficits. Sudden and steep reductions in subsidies, however, lead to a decline in fertilizer consumption as has happened in India in the 1990s. As PF technologies can facilitate higher yields with the same, or even less, inputs while simultaneously conserving the soil and water, their rapid adoption in Asian farms is essential.

PF technologies can contribute to sustainable land management in Asia, where per capita arable land availability is only 0.23 ha against 1.51 ha in the rest of the world (FAO, 1993). They can be used to preserve the land's potential for multiple uses in many ecosystems of Asia. In some countries, we see an increasing trend of farmers being forced out of traditional farming, willingly or unwillingly, mainly because of land and labor shortage, urban demand and general economic development. In countries such as Japan, Korea, and Taiwan, both demographic (ageing population) and market changes are pushing farmers to make decisions that are both profitable and environmentally sound. In such conditions, automation of data collection and implementation can surely lead to an improved decision making.

Population gains, improved diets, shifts toward increased meat consumption and a growing emphasis on environmental issues also call for adoption of PF in Asia. Globalization of markets in the new millennium, which enables entry of new producers into the market place for farm products that were formerly the exclusive preserve of Asian countries, is also expected to force Asian farmers to be more competitive. For example, USA, Israel and Canada are now producing premium Basmati rice, bananas and kenaf fibre respectively. In order to enhance market competitiveness in both cost and quality, Asian farming must be made more efficient than now through introduction of innovative technologies such as PF.

Besides farm management, PF technologies can contribute to agronomic research in many ways. For example, yield data can be used to an interpretative advantage in on-farm trials of new varieties. Varietal comparison can be simplified through mapping the differences in yield potentials of different varieties. PF technologies can provide the basis for valid small-plot trials, and optimal plot and block configurations for field experiments. Data gathered in PF systems can help in identifying areas with high pollution potentials, estimating loading rates of pollutants and assessing surface water movement of agricultural chemicals.

Many PF technologies are multi-functional and their adoption should result in favorable changes in various aspects of Asian farming. Asian farms have been traditionally worked by many generations of farmers, who accumulated substantial location-specific knowledge and skills. PF technologies allow integration of local knowledge into farm resource management (Tabor and Hutchinson, 1994) to create a historical spatial database that is useful for many generations. Further, the collection and analysis of georeferenced data from all fields in a village provides a unique opportunity to gain new insights into the functioning of Asian agricultural systems. The data will have added value, especially when integrated into regional databases. All these reasons suggest that PF technologies are, and will be, increasingly relevant to the development of sustainable cropping systems in Asia.

Asian farmers are often miscast as conservatives depending on old, outdated methods and technologies. Ample evidence exists however to indicate that Asian farmers can readily adopt innovations aimed at improving efficiency, if they find them to be beneficial and within their technological and economic reach. It is, therefore, vital to identify suitable opportunities for adoption of PF technologies in Asian farms.

Current Status and Opportunities for Adoption of PF in Asia

Recently, Asian countries have initiated efforts to promote PF. In Japan, the Ministry of Agriculture has been allocating funds for PF research since April 1998. Testing of PF technologies for rice at the research farm level is in progress at Kyoto, Tokyo and Hokkaido universities. Staff at Kyoto University recently developed a two-row rice harvester for determining yields on a microplot basis (Iida et al., 1999). Quasi-governmental organizations such as Bio-oriented technology Research Advancement Institution

(BRAIN), and private corporations and trading companies such as Mitsubishi, Omron, and Hitachi are looking into the possibilities of using high resolution imagery for PF applications. In Malaysia, the Malaysian Agricultural Research and Development Institute (MARDI) has initiated research on PF for upland rice (Mohamed, A.Z., Personal communication). In India, a few researchers in the private sector initiated PF studies in high value crops like cotton, coffee and tea. In Sri Lanka, researchers at the Tea Research Institute are examining precision management of soil organic carbon (Anandacoomaraswamy and Ananthacumaraswamy, 1999). Within each Asian country, however, some regions are in a better position to adopt PF technologies than others. In Japan, for example, Hokkaido is better placed than other prefectures because of its relatively big farms. Punjab and Haryana states, where farm mechanization is more common than in others, may be the first to adopt PF on a limited scale in India.

As noted earlier, PF is a suite of technologies and practices that can be implemented to optimize a wide range of farm operations including, but not limited to:

- Land preparation (type and depth of tillage, management of crop residues and soil organic matter, compaction reduction, post-harvest residue management),
- Planting (sowing date and rate, plant population and planting depth, varietal selection, crop rotation),
- Input management (rates and methods of use of fertilizers, pesticides, soil amendments, and water),
- Crop stress detection and monitoring (insects, diseases, weeds, and vegetation stress due to abiotic factors), and
- Harvesting (harvest dates, grain moisture content and quality).

As the above operations require diverse combinations of technologies and tools, there is no need to adopt all PF technologies at once to start benefitting from them. Many farmers can begin by using only a part of the technology, as even partial use can bring many benefits. In fact, applying the entire range of technologies is not profitable in several cases, particularly for technologies that are not scale-neutral. For example, small farmers in Asia cannot afford yield monitoring with combines and VRT, but large commercial estate farms and farm associations can use them, especially in high-value crops. In contrast, even small farms that are not highly mechanized can benefit from technologies such as GIS and remote sensing, which allow a better grasp of field characteristics and an earlier identification of stresses.

PF is likely to provide a greater profitability advantage for (a) high-value crops, (b) areas where input costs are high, and (c) areas where production conditions are very heterogeneous. In Asia, rice, wheat, sugar beet, onion, potato, and cotton among the field crops, and apple, grape, tea, coffee and oil palm among horticultural crops are perhaps the most relevant for PF. For each crop, however, the type of farm operation likely to get the most benefit from PF would determine the technologies to be adopted. Perennial crops such as oil palm, rubber, and cocoa account for nearly 85% of fertilizer consumption in Malaysia, because as much as 300-450 kg nutrients ha^{-1} $year^{-1}$ are applied on mature plantations (FAO, 1999). Adoption of PF techniques aimed at nutrient management will obviously be a priority for such crops.

Insect pest management through precision spraying may be attractive for crops like cotton as globally more insecticides are used on cotton than any other crop. Worldwide sales in insecticides amounted to about $12 billion in 1995 with cotton accounting for $1.8 billion. Over two-thirds of the world's cotton area treated with insecticides is in India, China and Pakistan, and as much as 40% of all insecticide sales in India are for cotton. Owing to excessive and indiscriminate use of pesticides, parallel increases in ecosystem poisoning and pest resistance have become major problems. Integrated pest management (IPM) has been recommended to reduce insecticide use but the detailed records required for IPM can make pest control more expensive over the years, because of increasing labor costs. Studies in USA suggest that PF technologies, which can help in detection and mapping of insect infestations, can be a useful component in IPM. Everitt et al. (1996) used airborne video imagery for detecting whitefly infestations in cotton fields and integrated the video data with GPS and GIS. Pest infestation could be detected in color-infrared and black and white near-infrared video imagery, based on whitefly deposits of sooty mold fungus on foliage. The integration of GPS with the video imagery permits the latitude/longitude coordinates of insect infestations to be printed on each image. The GPS coordinates can then be entered into a GIS to map insect infestations. PF technologies also enable entomologists to develop regional maps where insect infestations occur over large areas (e.g., locusts).

Hardpan development is a common problem in many soils of tropical Asia. Although distribution of hardpans is not uniform, farmers are advised to conduct subsoiling (deep soil tillage) every 3-5 years, which is expensive and labor-intensive. Studies at the University of Florida (Clark and McGuckin, 1996) showed that subsoiling needed to break only through the hardpan, indicating that subsoiling to any significantly lower depths is an unnecessary cost. With a penetrometer, a GPS receiver, and soil sampling, a subsoil strength map that can show the locations and the necessary depth for subsoiling can be created. A sensor to determine the depth, thickness and strength of the hardpan is in development at the University of Florida.

Perennial weeds such as *Imperata cylindrica* are major scourges in Asian cropping systems. Control of such weeds is both expensive and time-consuming. Using remotely sensed images and GPS, a weed distribution map can be created and used for determining the methods of control and the type of weeds to target with precision spraying. If weeds do not cause significant yield loss, PF techniques may not be necessary. Likewise, if weeds are evenly distributed, a broadcast application may be a more logical approach. In contrast, precision spraying can be effective to control hardy weeds that occur in patches. A weed distribution map used along with a subsoil strength map can help in optimizing the intensity of cultivation at various field locations.

With GIS software, a map of optimum plant populations can be created as a function of soil type and factors such as water status. Based on this map, sowing rates can be varied to optimize yields. Throughout Asia, agriculture is the main consumer of water. In Thailand, for example, agriculture’s share is as high as 90%. Water savings through irrigation management and precision delivery to crops are essential in Asia, where per capita water resources are declining rapidly. A topography map along with a plant population map can be used for optimizing the timing, amounts and placement of water in various field locations. Plantation owners, for example, can combine tensiometer information on soil moisture with a map of evapotranspiration derived from weather forecasts and then vary irrigation water to match crop demands. While possibilities for adoption of PF technologies are diverse and numerous, it is important to analyze constraints as well so that innovative approaches to overcome them can be devised.

Constraints for Adoption of PF in Asia

In a presentation at the 4th International Conference on Precision Agriculture held in 1998, I described in detail the various constraints to adoption of PF technologies in Asian cropping systems (Srinivasan, 1999). Principal barriers include:

- High cost of obtaining site-specific data
- Lack of willingness to share spatial data among various organizations
- Complexity of tools and techniques requiring new skills
- Culture, attitude and perceptions of farmers including resistance to adoption of new techniques and lack of awareness of agro-environmental problems
- Small farms, heterogeneity of cropping systems, and land tenure/ownership restrictions
- Infrastructure and institutional constraints including market imperfections
- Lack of success stories of PF adoption and lack of demonstrated impacts on yields
- Lack of local technical expertise
- Uncertainty on returns from investments to be made on new equipment and information management systems, and
- Knowledge and technological gaps including
    - Inadequate understanding of agronomic factors and their interaction,
    - Lack of understanding of the geostatistics necessary for displaying spatial variability of crops and soils using current mapping software, and
    - Limited ability to integrate information from diverse sources with varying resolutions and intensities.

Approaches for Adopting PF Technologies in the Asian Context

Extensive indigenous knowledge of Asian farmers on local variability of their farmlands confers a comparative advantage in application of PF techniques. However, PF technologies require some key changes in mechanisms of their development and delivery to farmers. For example, yield monitoring with combines and VRT are two most common PF technologies in USA but they are not yet within economic reach for many Asian farmers. Instead, remote sensing methods to monitor yield variations, and combinations of manual and mechanical methods for variable input applications may be more appropriate in the Asian context. It is also important to determine the aspects of PF that are practical at a field scale, and test pragmatic and affordable alternatives that are being developed elsewhere.

In most Asian countries, limited resources of small farms restrict farmers from using PF technologies. However, this limitation can be overcome through devising innovative cost sharing mechanisms and using freely available mapping software. Many types of PF tools can be considered for adoption in small farms but there is no single right way for all fields. In some cases, farmers do not need additional information on their fields but only better tools to analyze and interpret existing information.

One of the most useful PF concepts is the idea of identifying and distinguishing relatively uniform regions or zones within a field and developing a prescription for management of each zone. Definition of realistic management zones, however, requires considerable skill and knowledge of spatial relationships between yield and other factors. It is possible that some zones show economic response to variably applied herbicides but not fertilizer. Two common methods for developing management zones are intensive grid soil sampling and mechanical yield monitoring for at least 3-4 years. However, both these processes are time-consuming and expensive. Image data, however, can provide a comprehensive view of an area while maintaining spatial connectivity between small fields, thus reducing the need for complex spatial modeling. With the advent of high resolution satellites and decreasing cost of image acquisition, it is expected that aerial remote sensing can help to reduce the costs of mapping yield variations and defining management zones. Multi-temporal and multi-spectral analysis of images acquired during crop growth, and superimposing such images onto a cartographic database can help in identifying specific areas requiring the attention of farm managers and planners. Based on such analysis, the extension staff can advise farmers on how to divide their cropland into uniform zones and perform efficient soil-sampling methods that are less intensive than grid sampling. A software system such as SSToolbox may be used to perform various GIS and statistical analyses necessary to define management zones.

Getting started on a PF strategy in a village or a farm cooperative is not so difficult. The first step is to develop a basic farm plan based on past experience with specific fields, crops, farming practices, and resources available. Using a backpack GPS system, a progressive farmer with the guidance of a village extension officer can go around the field boundary and record the coordinates of each field in that village. Recording can be done by obtaining a GPS position every 20 meters or at selected points such as fence posts and known crop boundaries. If fields are reasonably big, GPS information can be recorded while driving in a tractor around the field boundary. A hand-held data logger can be used to record soil type and field condition. The extension officer can download the recorded GPS data into a computer and apply differential corrections to the position data before processing attributes or codes. Using a GIS program, a field boundary map can be created and each parcel's total area can be derived. Later, the georeferenced crop data can be overlaid onto existing digital maps of the block. In regions where land fragmentation and subdivision are not common, a single survey is adequate for field boundary definition, which can be used for many years. Once the perimeter map of all fields is complete, the area can be divided into small units and the address of each unit can easily be recorded.

During the crop season, a data logger can be used to record crop type and condition. If a parcel edge is a common boundary between two different crops, more than one attribute can be selected for each GPS position. Remotely sensed imagery obtained during crop growth can be used to detect and monitor any stresses within fields. A GPS receiver can be used later to guide the extension staff back to a specific location for obtaining a soil sample or for collecting insect data from a stressed area. The positional information of sampled sites can easily be entered into a GIS program. Any additional input applications in such stressed areas may be recorded. Farmers can continue to collect data using a spreadsheet template provided by the extension officer to build the farm database. Over time, the extension officer can add new layers -- crop history, landscape, basic condition of the soil and terrain, fertility, soil composition, weed location, crops and their yield, and other factors -- to the farm GIS database. The data can then be used for preparing soil type maps, crop history maps, fertility maps, input recommendation maps, etc.

Another approach, which may prove useful in leading the way to precision agriculture for farmers with limited resources, uses remotely sensed imagery as the starting point. A town office, farmers' association or PF service bureau can acquire remotely sensed imagery in the form of an aerial photograph or high resolution satellite imagery for the area of its interest. Farmers (in the case of estate farms) or local governments may share costs of acquiring and processing imagery. The first step is to georeference the image in a desktop GIS such as ArcView or MapInfo, by selecting well known positions as ground control points, and create a base map for all fields. The base maps can be individually delivered to farmers through the Internet and then viewed and printed with free software such as ArcExplorer. As part of this map production, all existing data about the farm can be added. Standard data templates may be distributed to the farmer to enable him to add new data every season. After adding new data, a copy of the spreadsheet is sent by the farmer (or extension staff acting on behalf of farmers) to the farmers' association office for updating the files. Orthorectification and superimposition of cadastral information on images can give a lot of information on fields. It allows accurate calculation of the individual field areas using the tools in GIS. The town office staff can use a GIS as a development tool to create files containing historic information. Problem areas can easily be delineated in a GIS by drawing regions around them. A service provider with GPS facility can sample such problem areas during the crop season so that one can avoid costly sampling of a large area.

In the following year, locations for soil sampling can be chosen by overlaying a grid on both stressed and normal areas of the field. The number of samples may be varied depending on level of stress. After collecting and analyzing soil samples from normal and stressed areas, results can be entered by location in a GIS and a map can be created for each analyzed variable. In order to reduce costs in variable rate application of inputs, it is better to first target problem areas by applying the extra inputs necessary and then apply inputs uniformly across the field. Using a GPS receiver, weak spots in a field can be outlined and spot-treated even before planting. If another image is acquired after crop emergence, it is feasible to identify weak spots that were unnoticed earlier. An image acquired during reproductive growth can show further weak spots that may be corrected before final harvest.

A third approach -- perhaps suitable for estate farms or relatively big farms owned or leased by private corporations -- uses sophisticated technologies such as a multi-spectral digital video imaging system, and high-end GIS and remote sensing software. The imaging system uses specially filtered video cameras mounted in aircraft to detect selected frequencies of visible light and infrared energy reflected from the ground. Unlike satellite data, video-recorded images based on the green (555-565 nm), red (625-635 nm) and near-infra red (845-857 nm) regions of the electromagnetic spectrum can be viewed and analyzed as soon as the plane lands. Imagery may be captured at altitudes of 1200-1400 meters under sunny conditions. Analysis of imagery can allow delineation of management zones, based on which crop production decisions may be made.

Implications for Adoption of PF in Asia

Some researchers consider that PF can help in triggering the next Green Revolution. The past Green Revolution, which is now fading, had strong positive and some negative impacts. An assessment of the implications of adoption of PF in the Asian context may help policy makers minimize negative impacts, if any. The following issues are worth examining.

- **Adoption patterns:** As agriculture is an intrinsically conservative business, any major technological development takes much time and effort before it is adopted by a majority of farmers. It took 25 years for hybrid seeds to catch on and more than 30 years to see tractors fully utilized (Robert, 1999). A similar course must be expected for PF. Because diverse cropping systems, land quality, economic and geographic conditions characterize Asian farming, adoption patterns of PF are likely to be diverse. Even for selected crops, while some farmers may use the Internet to discover marketing opportunities, others may use PF solely for in-field decision making. Owing to relatively high cost and complexity, adoption process will not occur uniformly over time. Individual small farmers in Asia are likely to adopt them slowly, while estate owners and farmers' associations may adopt quickly. PF in Asia is likely to evolve as a combination of services and products mainly taken up by farm associations and the private sector, which can spread the capital costs over large area and over many years. Diffusion of PF is likely to be more rapid in areas surrounding cities and in areas with larger numbers of farm consultants and dealers.

- **Environmental implications:** A more precise use of external inputs through PF may alleviate environmental pollution from Asian agriculture in the long term. However, as in all countries, downstream effects of increased soil erosion, water use, nutrient and pesticide leaching are ordinarily of national concern and of little interest to individual farmers. Only those PF technologies that prove economically profitable are likely to be adopted first. The major challenge, therefore, is to design PF innovations and incentives that are financially rewarding to individual farmers as well as environmentally sound and beneficial to the society as a whole. Synergy between PF and biotechnology may also lead to environmental improvements (NRC, 1997). If there are yield penalties with genetically modified varieties for increased herbicide tolerance, those varieties can be sown in areas with high weed infestation. Likewise, varieties with insecticidal properties may be planted in potential problem areas with pests.

- **Economic implications:** Although profits for large farms, which are likely to adopt PF technologies first, are expected to be high, small farmers too can get economic benefits over time through adopting only proven technologies. Adoption of profitable technologies also should lead to increases in the value of land.

- **Employment implications:** PF requires significant supporting infrastructure in the form of skilled labor, software development and hardware availability. Therefore, new industries providing PF services, PF products and combination of PF services and products are likely to emerge, which in turn should provide additional employment. For example, agricultural consulting firms specializing in equipment, service, and technology delivery can develop to supply the needs of big farms adopting PF. In cooperation with local governments, they can assist in setting up farm GIS databases, process and analyze data to create maps, reports, statistics and recommendations for farmers in a given area. New opportunities may also arise in the form of VRT, equipment sales and recommendations, geoprocessing, etc. All these services will generate massive amounts of data, which obviously requires skilled personnel with knowledge and experience to interpret the data for guiding the decision process.

Future Action

In order to promote PF technologies to foster sustainable agricultural development in Asia, many policy and technological initiatives have to be undertaken at regional, national, provincial and local levels. Some of those issues are discussed below.

- Appropriate capabilities, policies and infrastructures must be created in the Asia-Pacific region to exploit PF technologies suitably and effectively. Many Asian countries started late in adopting the industrial revolution but they must not fall behind in adopting the information revolution in agriculture. Goal setting mechanisms must be evolved for identifying the most suitable PF approaches specific to various agro-ecological and socio-economic conditions. Partnership arrangements among research and extension agencies must be promoted to develop PF applications that are most economically beneficial and technically practicable, and to devise new methods of cost sharing and fine tuning of technology to make it affordable. Rapid developments in the Internet-based information delivery systems are expected to make some PF technologies affordable for farmers. Regional and inter-country cooperation pacts for conducting research on PF technologies of mutual interest should be reinforced. Moreover, since the capacity of institutions varies from country to country, a complementary mix of institutions may be a better way to achieve this. The Asia-Pacific Sustainable Agriculture Research and Application (APSARA), which was proposed at the last meeting (Hullar, 1998) can contribute substantially in developing a program on priority areas and a mix of the most appropriate PF technologies to attain the goals.

- Within each country and various regions within a country, research to identify the most suitable crops and farming systems for applying PF technologies must be intensified. The immediate needs of Asian cropping systems must be considered while formulating PF research projects. Because PF technologies do not come with a guarantee of success in all situations, it is important to determine how to apply them especially at the level and scale of operation now possible in the Asian context. It is also necessary to localize and modify certain components of technology to meet specific requirements. While it is essential to study the latest innovative PF technologies all over the world, it is more important to determine what is relevant and what is not.

- Inadequate research and institutional support in Asia is a major constraint for adoption of PF technologies. In order to make scientific developments in PF a commercial reality, due attention should be paid to the development of capabilities and institutions. Advances in PF applications will continue to occur in industrial countries in future. Asian countries must be aware of those advances and make their own contributions through evaluating available technologies for suitability and removing any existing problems. They also must make cost/benefit assessments and informed judgments on the outcome of introducing PF technologies in social, economic, environmental and institutional terms and in regard to sustainability.

- Appropriate policies and measures must be established at various levels to enable PF adoption from a solely "technology-push" to an application-driven approach, and create the right environment for active partnerships among government, the private sector, R&D organizations and NGOs. Because no single establishment can take on the entire PF process -- which consists of data logging, point sampling, data analysis and spatial modeling (Berry, 1998) -- it is vital that various agencies join together and contribute their relative advantages in knowledge, skills and experience. Participatory learning is crucial to effective implementation of PF technologies. Therefore, local knowledge must be actively sought and incorporated during planning. This, however, requires close collaboration among farmers and farmers' associations, community groups, NGOs, spatial data providers, data analysis firms, machinery manufacturers, research and extension agencies, and local governments. Mechanisms to sustain such collaborative activities must be set up.

- Low or non-availability of personnel to conduct research on PF technologies relevant to Asian conditions is another issue to be addressed. As indigenous research capacity is vital for sustained progress in application of PF technologies, governments must allocate adequate budgets and ensure rational utilization of funds as per well-chosen priorities. As farmers and associations may not readily agree to share their datasets, government agencies and NGOs should promote models and templates for data sharing and provide examples of benefits of sharing and aggregating data.

- The important role of the private sector and the proprietary nature of many technologies must be recognized in the context of development of PF technologies. Governments, therefore, should assist the private sector to create suitable PF applications tailored to the needs of specific agricultural conditions and design ways for effectively integrating technologies in current field operations in Asia. For example, data collection hardware and software, information management software and GPS devices must be user-friendly to be operated by individuals who are novices to these technologies. There is also an urgent need to make fully functional farm GIS easier for nonspecialists to learn and use. Innovative ways on how the private sector can work with farmers, governments and other institutions in promotion of PF technologies must be explored. Greater investments in PF technology transfer are also necessary, perhaps through promoting support services to NGOs and the private sector.

- Farmers' associations and community-based organizations in each country can play a significant role in promoting sustainable agriculture through shared access to PF technologies. If PF is considered a series of discrete services such as map generation, crop scouting, etc., it is possible to fit these services within the structure of a progressive farm cooperative in each Asian country.

- Remotely sensed high resolution imagery may become more important for assessing crop and soil variability than yield maps in Asia. Therefore, it is important to concentrate on developing robust image analysis methods for farming in the form of, for example, a good quality product of reflectance and an interpreted product based on which farmers can actually make decisions. New cost-effective methods for classifying fields and creating management zones within a village must also be developed.

- As technology for gathering information is far ahead of our understanding of how to use it to help growers make decisions, knowledge-based systems must be developed quickly to realize full potential from PF. In this connection, development of the ability to use available field information and experience, to form relationships among the various GIS databases and to deduce reliable decision-making information is essential. By building farm databases and adding more information to create models, decision support systems that suit the needs and resources of Asian farmers can be developed. Analytical procedures to monitor and manage spatial and temporal yield variation of crops must be simplified. Likewise, research on PF technologies for effective resource management on a watershed basis must be promoted.

- The long-range goal should be to assist Asian farmers in the practical and cost-effective use of PF technologies so that they can maximize profits and make good crop production and management decisions. Some methods to help farmers include:
    - Conducting pilot demonstration projects and offering training seminars for farmers to show correct and cost-effective use PF technologies,
    - Providing institutional credit for adoption of PF technologies,
    - Processing generated data and providing user-friendly summaries that will help farmers in making correct decisions, and
    - Contributing the technical expertise to integrate various PF components for each farmer's specific application.

Epilogue

Information management and its use in practical decision making at the farm level will be the foundation for sustainable agriculture in the new millennium. PF, which benefits from the emergence and convergence of many information technologies, can offer a sustainable agricultural system that permits farmers to efficiently manage their fields and to conserve farm resources. PF is revolutionary from one perspective, but from another viewpoint it is only a natural evolution in the use of technology to cultivate land better. The Asia and Pacific region has many serious agro-environmental problems due to its ever-increasing population, diversified lifestyles, farm practices, changing land use patterns, and varying conditions of climate, terrain, flora and fauna. PF technologies may be seen as tools to complement the efficacy and effectiveness of conventional approaches to solve some of those problems. As environmental benefits alone do not create an incentive for adoption, PF must be popularized in Asia as an integrated farm management approach for optimizing yields and profits based on the inherent productivity of each field unit.

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