A Conceptual Framework for Precision Agriculture in Oil Palm Plantations

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INTRODUCTION

Since the advent of estate agriculture planters have recognized the importance of keeping agronomy records over complete crop cycles.

One of the earliest attempts to develop a comprehensive and integrated record keeping system for plantation crops was designed by London Sumatra in Indonesia (Rosenquist *et al*., 1975). Agronomy data for each field was stored on a 'clip card' that provided space to enter basic data for each year in a single planting cycle. The cards provided a means to record and store most of the important agronomic parameters measured on estates. They also provided the means for selecting plantation fields according to a limited range of parameters. The edge of each card was perforated with holes that could be clipped to denote the status for the field. Thus, fields fulfilling a particular criteria could be selected by inserting a needle through the representative hole in the clip card.

This simple system was used in many of the London Sumatra estates from the 1960s to the 1980s. Agronomists found it helpful to review long term data on yield, leaf nutrient levels, fertilizer inputs, and palm stand for each field during field visits and for the preparation of fertilizer recommendations. The clip card system, which predated the introduction of computers in plantations, was a milestone in the development of tools for improved plantation management. The developers also envisaged the clip cards as the precursor of a fully computerized system in the future (Rosenquist *et al*., 1975).

Some use was made of mainframe computers in the major estate agriculture companies during the 1960s and 1970s, but their application was constrained by the cost of equipment and the specialized knowledge required to operate the programs, such that agronomists were not usually able to make use of the stored field data without the assistance of computer specialists.

Personal computer (PC) use has only gained widespread acceptance since the 1980s with the introduction of user-friendly spreadsheet and database software. Spreadsheets are a convenient tool for the storage and analysis of simple and discrete data sets but become unwieldy and difficult to maintain when a large number of parameters is recorded for each plantation field in an estate over a period of several years. Thus, the storage and analysis of complex data sets can only be achieved satisfactorily with database management systems (DBMS) that are now the standard tools for data storage and analysis in a wide range of applications. It is therefore, at first, surprising that DBMS have so far been adopted on such a limited scale in the plantation industry. One explanation is that to be effective plantation agronomy DBMS must be easy to use by estate clerks for data entry and provide managers with the means to analyze and summarize data easily.

The introduction of precision plantation management tools in many companies has been frustrated by:

- Poor linkages between different technologies (e.g. accounting, mill weighbridge and field agronomy software);
- Lack of flexibility in the tools, poor understanding of the aims and objectives of the technology;
- Limited understanding by computer programmers of what is required by planters; and
- Concern that the new technologies will divert management staff from their responsibilities in the field.

Agrisoft Systems and the East & Southeast Asia Programs (ESEAP) of the Potash & Phosphate Institute (PPI) and the Potash & Phosphate Institute of Canada (PPIC) have cooperated with Pacific Rim Palm Oil Ltd (PRPOL) to develop an effective Agronomic Management Information System (AMIS) to improve upon the basic principles found in the now redundant clip card model (Fairhurst *et al*., 2000; Rankine *et al*., 2001; Griffiths *et al*., 2002).

The purpose of this chapter is to describe the use of tools for the analysis of temporal and spatial variability in agronomic parameters and how this information can provide managers with the means to introduce appropriate levels of ‘precision’ or ‘site-specific’ management techniques in oil palm plantations. We provide illustrations based on experience gained during the development and implementation of this technology.

WHAT IS ‘NEW’ ABOUT PRECISION AGRICULTURE?

In the past, experienced and capable planters could implement a degree of ‘site-specific’ management based upon:

- Intimate knowledge of field characteristics gained over many years of intensive field inspections;
- Reference to (often limited and fragmented) quantitative and qualitative information gathered from field surveys and field recording; and
- The results of soil and plant analysis.

The very high standards of field maintenance achieved in plantations in the 1960s and 1970s coincided with an era when each estate was comparatively small (<5,000 ha). Such intensive management approaches are, however, no longer feasible in most plantations, because managers at all levels are presently required to oversee much larger areas than in the past. Furthermore, existing methods of agronomy data management make the necessary data analysis very difficult, time consuming and tedious.

The new standard of precision plantation management, then, comprises the use of tools for data collection and analysis that provide the manager, now responsible for much larger areas, with all the information required to vary the allocation of inputs according to identified needs.

For example, a full historical record of yields, leaf nutrient status, and soil fertility status is required to make accurate predictions of nutrient requirements, and mapping can be used to identify accurately areas where soil conservation is required. Another feature of precision plantation agriculture is the use of a DBMS to identify fields that meet particular criteria (e.g. large yield gaps, low leaf nutrient status) and then implement corrective action.

An essential prerequisite of precision plantation management is that there is capacity within the plantation management team, in terms of human resources, time and skills, to implement field activities according to each field’s particular agronomic requirements. This important point should be considered before embarking on costly measures to gather and process information at a more detailed level.

GOALS OF PRECISION AGRICULTURE

The aim of precision plantation management is to vary the allocation of production inputs (mainly labor and materials) on a field-by-field or palm-by-palm basis so that each field or palm within the plantation reaches the maximum economic yield. This cannot be achieved, of course, by implementing standard work programs for field upkeep, nutrient management and pest and disease control across all fields within the plantation. Instead, knowledge of the particular condition of each field (e.g. productivity, soil properties, leaf nutrient status,) is used to guide the allocation of inputs.

For precise management of inputs an AMIS must be organized so that managers and agronomists have access to all the information required to vary the supply of plantation inputs according to need. Clearly, the return on an investment in more precise input management will be greatest in plantations where there is a high degree of spatial variability in factors affecting productivity (e.g. soil type, planting material, topography).

In theory, the ultimate goal of precision agriculture is to vary input use and management operations on a palm-by-palm basis, but the feasibility of this is related to the characteristics of each field operation. For example, selective palm thinning is usually carried out based on the assessment of each individual palm, whilst the implementation of soil conservation and pest control measures often includes only parts of a particular field. Information on palm and soil nutrient status is usually based on samples collected from a number of palms distributed within each field which are combined to produce composite samples that are then analyzed to give a single value for the field.

By contrast, recommendations for fertilizer inputs (paradoxically the most costly variable-cost item), are usually only provided on a field-by-field basis. Irrespective of the particular operation, precision agriculture tools provide opportunities to improve the match between the allocation of inputs (labor and materials) and palm requirements.

With more careful planning of inputs according to need, the risk of environmental pollution from fertilizers and other agro-chemicals being applied at greater than optimal levels can be reduced, and traceability, an important requirement for food products, can be improved (Godwin *et al*., 2002).

I Collection and storage of agronomic data for use in precision plantation agriculture

The development of precision plantation agriculture centers on the use of four technologies, all of which have been developed over the past twenty years (Table 1).

It is important to choose the most appropriate tool for gathering agronomy data and we will now review methods of collecting each type of data that have relevance to nutrient management.

We use OMP, a DBMS written in Microsoft Access™ that provides the means to store and analyze data for all agronomic parameters (data on yield, fertilizer use, environment, climate, leaf and soil analysis, pest and disease, and tree census) for each field over several planting cycles.

Trimble Pathfinder™Global Positioning System (GPS) equipment and software (Geo Explorer™ Data Collector and Pathfinder Office™ Software) are used to collect geo-referenced information (point and line data) for use in mapping. A data dictionary can be set up in Trimble Pathfinder™ GPS, then uploaded to the Trimble Geo Explorer Datalogger, that greatly facilitates consistent data collection. Summary data for each field is prepared by extracting data from the GPS data outputs.

We use ArcView™ and MapInfo™ software to produce maps, integrating data from the OMP DBMS and GPS dataloggers.

Technology was developed in three of PRPOL's estates (PT Asiatic, Jambi province, Indonesia; PT Harapan Sawit Lestari, West Kalimantan; and Milne Bay Estates, Milne Bay Province, Papua New Guinea).

IKONOS™ satellite images have been used for palm counting and estate development planning.

Table 1. Basic tools for the implementation of precision plantation agriculture.

Tool	Data collection	Comments
Agronomy database management system (DBMS)	Storage and analysis of agronomy data at field by field scale. Reports detailing historical trends in e.g., production, leaf nutrient status. Basic data source for use in GIS applications.	Agronomy database must be integrated in the estate data processing system so that raw data is captured efficiently and, if possible, directly from the source. Error checking and analysis is much easier to perform in a database than in spreadsheets.
Global Positioning Systems (GPS)	Collection of geo-referenced point data (e.g., palm survey), line data (e.g., drains, roads) and area data (e.g., field areas).	Indispensible for collecting georeferenced information. Some GPS mapping functions can also be achieved using satellite images.
Geographic Information Systems (GIS)	Integration of DBMS and GPS to provide spatial representation of data and information. Maps showing spatial analysis of e.g., yield, yield gaps, palm nutrient status.	Must be linked to a database containing historical agronomic data.
Satellite images	Identification of field boundaries, delineation of buffer strips, coarse palm census, canopy analysis.	Basic palm *counts* are feasible but palm *census* (stand composition, pest incidence) cannot be derived from satellite images alone.

As we shall see, for much data collection, leaf sampling unit (LSU) palms located every tenth palm in every tenth palm row, provide a useful fixed grid of sampling points (1.36 points ha^{-1} at 136 palms ha^{-1}) that can be used not only as a reference for leaf sampling but also for environmental and pest and disease data collection.

Soil mapping

Data on soil texture (based on a finger test), slope position (using a hand-held clinometer) and soil type can be collected at each LSU palm and portrayed in maps using GIS software to interpolate the individual data points. Soil maps showing continuous variability can then be used as overlays to relate productivity and nutrient status to soil characteristics. Discrete variability maps can also be produced that show a single value for the prevailing soil type in each field.

Bunch production

The conventional approach is to gather information on the number of bunches harvested during each harvesting round in each field. This is then used in combination with production records kept at the plantation weighbridge (tonnes per field) to calculate yield data (t ha^{-1}; kg bunch^{-1}; bunch palm^{-1}) for each field in the plantation. Surveys at PRPOL have shown that productivity varies widely within individual fields and some plantations are now investigating the possibility of collecting separate yield information for each bunch collection platform (i.e. every 0.25 ha).

It may even be possible to collect yield data for each palm, using portable weighing equipment, bar code palm identification and a global positioning system (GPS), but the cost of data collection and equipment precludes this approach at present.

Fertilizer application

The usual practice is to record the amount of fertilizer material applied per palm, based on fertilizer recommendation schedules. This is unsatisfactory because it is difficult to calculate summary data showing the *total* nutrient supply from fertilizers, palm oil mill effluent (POME) and empty fruit bunches (EFB), and furthermore, the amount applied in the field (kg palm^{-1}) may differ considerably from what was recommended. We advocate that the total amount of fertilizers, POME, and EFB applied (tonnes per field) be recorded and nutrient inputs (kg palm^{-1}) be then calculated based on the nutrient content of each material and the palm stand.

In the future, it may become interesting and feasible to vary fertilizer inputs within each field according to yield records kept for each harvest platform or palm, particularly where it is possible to mechanize fertilizer application. Varying the rate of fertilizer within each field may be possible, based on maps showing the distribution of soil types, but varying fertilizer rates on a palm-by-palm basis is not likely to become feasible in the foreseeable future.

Environment

Most plantations are presently intensifying their efforts to collect particular environmental data regularly. We use a set of appropriate qualitative descriptors to describe aspects such as erosion, drainage and groundcover. Data is collected by assessing conditions at each LSU palm and storing the information in a DBMS. GPS equipped with data logging and dictionary facilities can be used very effectively for such data collection because:

- Each sampling point is geo-referenced;
- A data dictionary can be installed in the GPS that ensures consistent data collection; and
- Data quality is improved since the data collector *must* visit each palm to complete the survey.

Medium to high-resolution satellite images also provide a cost-effective means of identifying problem areas (based on canopy density and color), as well as identifying field boundaries and delineating areas that should not be planted (e.g. creek and river sides, areas with unsuitable soil) in new developments (Paramananthan, this volume). In PT Harapan Sawit Lestari, areas that should not be planted along creek sides have been identified from an IKONOS™ satellite image (see Plate 1a). Boundaries are then shown in maps which can be used as the basis for field implementation.

Satellite images are a very useful way of documenting the *status quo* at the time of land purchase and provide a historical record for reference during possible land disputes. As satellite images become more affordable, it may be worthwhile to purchase an updated image at intervals of one to five years.

Pest and disease

As with environmental data collection, GPS can be used to gather information on pest occurrence by assessing each palm point (detailed survey) or LSU palms (coarse survey) for the presence of each pest and disease. Provided a data dictionary has been set up in the GPS, data on, for example, *Oryctes* beetle damage, *Ganoderma* and crown disease can be collected when the palm census is carried out (see below). Field summary data are stored in the DBMS and palm point data can be interpreted using GIS and displayed in continuous variability maps.

Recent high resolution (e.g. SPOT™, IKONOS™) satellite images may also be used to determine the extent of pest outbreaks (e.g. *Ganoderma* damage, caterpillar or bagworm attacks).

Leaf and soil analysis

Composite leaf and soil samples are usually prepared from samples collected from each LSU palm. Leaf and soil analysis data should be stored in a database that then provides a record of changes in nutrient status in each field and other essential information required for the preparation of site-specific fertilizer recommendations.

GPS equipment can be used during leaf sampling to record additional parameters such as a score for visual deficiency symptoms, the petiole cross-section, frond production rate, and palm height (Foster, this volume).

Palm census

The conventional approach is to collect data for each palm in each field. A worker visits each palm, records its condition and then prepares an isometric map showing the distribution of planting points and palm types within each field. This can now be done by recording data for each palm with a GPS, set up with a data dictionary that includes descriptors for each palm type (mature, immature, supply, dead, vacant, unplantable).

Alternatively, algorithms have been developed to interpolate high resolution (e.g. SPOT™, IKONOS™) satellite images and provide quite accurate counts of the number of palms in each field (Mandeville, P., pers. comm.; Liew, 2001).

Climate

A minimum data set includes data on rainfall (amount, number of days) and solar radiation recorded on a daily basis and summarized for each month. The Centre Coopération Internationale en Recherche Agronomique pour le Développement (CIRAD) has developed a simple method of calculating water deficits on a daily and monthly basis (Boutain, D., pers. comm.), and such calculations should be performed routinely on collected rainfall data (see Plate 1b).

Each field should be assigned to the closest rainfall station (not necessarily the one at the divisional office) so that climatic data is correctly linked to each field. In addition to standard climatic data (Anon, 1982; Anon, 1983a; Anon, 1983b), plantations should consider installing a pluviometer because a record of the timing of rainfall events helps with the prediction of optimal times for nitrogen (N) fertilizer application and thus reduces N losses by volatilization (Goh *et al.*, this volume).

II Data analysis and interpretation

All agronomy data collected from the field, mill weighbridge and plantation offices is integrated in a DBMS that provides plantation management staff with the means to:

- Store data over the lifetime of the plantation;
- Carry out spatial analysis ('discrete' and 'continuous' variability maps);
- Carry out temporal analysis (historical reports of field, division and estate performance); and
- Analyze other *ad hoc* data (Figure 1).

Analysis of agronomic data using DBMS

Clearly, a large amount of data accumulates each year for each field in the plantation, and agronomy DBMS and geographic information system (GIS) software are required to convert raw data (e.g. tonnes field^{-1}) into information (e.g. t ha^{-1}) and then information into knowledge (reports, maps) that can be used to improve field management. The agronomy DBMS is used to record, store and analyze data recorded on a field-by-field basis. It can be used to extract summary data (e.g. mean petiole cross-section value, mode value for erosion scores) for data collected at each palm point or LSU palm.

The database system provides reports that summarize data at the field, division and estate level and contains built-in tools for particular kinds of data analysis (see below). The agronomy database is also used to prepare, maintain and summarize the source data for use in the plantation GIS so that field data can be projected in practical management maps.

Mapping plantation agronomic information

Information presented in maps is generally considered easier to use by plantation management staff than tabular data. For example, it is more useful to provide the manager with a map showing blocks classified according to leaf nutrient status than a table showing the results of leaf analysis. All GIS software provide tools to link maps depicting field areas to a database, using the field name as a common identifier (Fairhurst *et al.*, 2000).

Three types of maps can be produced from plantation agronomy data (Table 2):

- Summary values (i.e. a single value for each field) can be projected in maps that use a color gradient to show *discrete* data

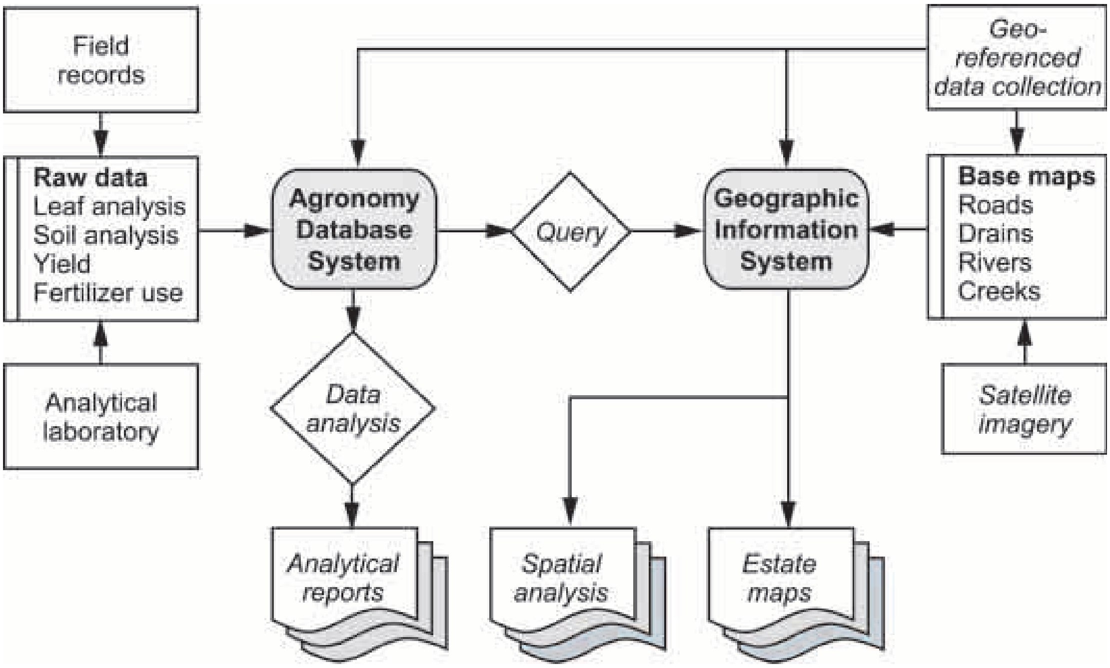

Figure 1. An agronomy management information system (AMIS) incorporates the use of database management systems (DBMS), global positioning system (GPS), satellite images and geographic information system (GIS) technology to store and analyse plantation agronomy data.

variability, the standard for displaying yield and leaf nutrient status information.

- Geo-referenced data collected from each single palm or LSU palm can be portrayed in *point* maps where individual points are classified by color or shape and shown as an overlay in combination with field area maps.
- Geo-referenced data collected from each palm or LSU point can be interpolated and projected in contour overlay maps showing *continuous* data variability. Continuous variability maps are useful for mapping ground conditions (e.g. erosion, ground-cover).

When planning the implementation of GIS it is important to decide what map type is most appropriate (Table 2). For example, continuous and discrete variability maps are suitable for portraying qualitative environmental parameters whilst discrete variability maps are used to portray yield information.

Three main types of satellite image are available in Southeast Asia and can be integrated in the GIS:

- LANDSAT is the least costly image available but provides low resolution at about 12 m. This is useful for identifying soil types and moisture stress but does not provide sufficient resolution to view individual palms.
- SPOT™ is more costly than LANDSAT but provides resolution at 2.5–5 m, which is sufficient to perform counts of mature palm crowns if the palm stand is healthy. SPOT™ provides insufficient resolution for counting young palms and where the canopy has been damaged by, for example, *Ganoderma*.
- IKONOS™ is the most costly image available and provides resolution at 1 m. Each detail of the plantation can be discerned and palm crown counts can be performed even on young palm stands. There are two types available:
  - Panchromatic (black/white) images (very high resolution and an excellent base for delineating individual field boundaries and for palm crown counts);
  - Multi-spectral images (256-color version of the panchromatic image but at a greater cost).

Table 2. Treatment of agronomic data to produce continuous, discrete and point variability maps.

Item	Parameter	Data source	Units	Frequency of observation	Mapping possibilities		
					Continuous	Discrete	Point
Environment	Ground cover, pruning, erosion, drainage, soil conservation	DBMS GPS	Qualitative descriptor. Single value for each field or LSU palm	Annual survey	Yes	Yes	No
Site characteristics	Previous land use, topography, land clearing method	DBMS	Qualitative descriptor. Single value for each field	Survey at planting	No	Yes	No
Pest and disease	Affected area, severity, control measures	DBMS GPS	Single value for each field or LSU palm	Periodic	Yes	Yes	Yes
Nutrient management	Leaf nutrient deficiency symptoms, petiole cross section, palm height, frond production rate	DBMS GPS	Single value for each field or LSU palm	Annual survey	Yes	Yes	Yes
Soil mapping	Soil type, soil properties	DBMS GPS	Single value for each field or LSU palm	Survey at planting	Yes	Yes	No
Palm census	Tree status (mature, immature, supply, abnormal, dead, unplantable)	DBMS GPS	Single value for each field or LSU palm	Periodic survey	Yes	Yes	Yes
Production	Yield, potential yield, yield gap	DBMS	Single value for each field (t ha^{-1}, kg $bunch^{-1}$, bunch $palm^{-1}$)	Monthly and annual data	No	Yes	No

UTILIZATION OF AGRONOMY MANAGEMENT INFORMATION SYSTEMS (AMIS)

Data collection and analysis is not an end in itself, and an AMIS is only useful when managers integrate improved knowledge of the plantation in day-to-day management and work planning. Some practical examples of how ‘knowledge based’ approaches can be used by planters and agronomists to increase productivity and nutrient use efficiency are discussed in the following section.

In the past, constraints with data analysis meant that most data analysis involved comparing performance between fields, divisions and estates. With AMIS it is also possible to conduct multivariate analysis based on differences in the natural resource base (e.g. soil) or differences between planting materials and planting years.

I Yield gap analysis

The most informative measure of plantation productivity is to calculate the yield gap for each field in an estate. A land capability classification unit, based on the soil types found in the estate and for which a yield projection for attainable yield has been drawn up, is assigned to each field. The yield gap (i.e. the difference between actual and attainable yield) is then calculated in the agronomy database, and this data is projected in field maps.

A yield gap analysis map of PT Asiatic Persada, an oil palm plantation in Jambi province, Indonesia, currently under rehabilitation, shows that the largest yield gaps occur around the estate perimeter due to poor infrastructure and palm maintenance (see Plate 2). The map is then used to plan and implement remedial action in those fields where there is the greatest potential to increase yield. In this way management time and resource utilization can be deployed in those areas with the greatest scope for increased returns (Griffiths *et al*., 2002).

II Planting material selection

When planning the selection of planting materials for new developments or replants, it is always useful to compare the performance of different planting materials according to palm age (years after planting) and under the different soil types in the plantation. Clearly, this would be extremely time-consuming unless all the required data parameters have been stored in a database with the capacity to analyze and retrieve data.

Yield performance of different planting materials can also be depicted in maps where planting material is identified by a color scheme and yield is shown in a bar chart attached to each field within each field in the map.

III Efficient nutrient management

Leaf analysis and soil analysis data, and information on visual deficiency symptoms stored in the agronomy database can be transformed into nutrient status maps where fields are classified according to a simple key that separates blocks into ‘deficient’, ‘low’ and ‘sufficient’ categories (Foster, this volume).

In PT Asiatic Persada, fields with low P status appear to be clustered together in groups that relate to differences in soil fertility and topography (see Plate 3). Managers and agronomists use these maps, in conjunction with block yield and nutrient status reports (see Plate 4a), yield gap analysis maps, recent satellite imagery and field inspections to determine the causes of poor nutrient status. Recommendations for corrective action include supplemental fertilizer applications and soil conservation measures where erosion and surface runoff have reduced fertilizer efficiency (Goh *et al*., this volume).

IV Natural resource management

Because data is collected, stored, analyzed and presented in a systematic way, AMIS is readily applicable to the requirements of ISO 9000 (quality management) and ISO 14000 (environmental management) systems (see Plate 4b).

ISO 9000 is based on several quality management principles, two of which are continuous improvement and a factual approach to decision making. Better decisions leading to better practice will contribute to the continuous improvement process. AMIS is not only a decision support tool but also can be used to demonstrate the benefit, or otherwise, of past decisions through analysis of post decision data. Furthermore, AMIS ensures that there is transparency in the decision making process.

The requirements of ISO 14000 for recording, reporting and taking action on environmental parameters relating to production, soils, fertilizer and chemical use, climate, etc. are comprehensively covered by AMIS.

Maps showing the spatial distribution of particular erosion problems on a field-by-field basis (see Plate 5a), or in continuous variability contour diagrams based on the interpolation of data collected at each LSU point (see Plate 5b), can be used to target remedial measures. Later these maps can be used to assess improvement progress. Clearly, a continuous variability map is more useful when planning remedial action for eroded fields than a map showing only a single value for each field (see Plate 5).

VI Isometric palm mapping

Palm survey data collected at each palm point with a GPS is used to produce isometric 'point' maps using GIS software (see Plate 6). This is probably the most appropriate approach for new plantings since GPS performs well under open sky. In mature plantings, it is possible to geo-reference the position of boundary palms and then use GIS software to predict the location of each planted point within the field. Point data could be collected from palms under a dense canopy with Trimble GPS equipment, which has advanced satellite and tracking characteristics able to pick up signals even where the canopy is quite dense.

CONCLUSIONS

GPS, agronomy database software, satellite images and GIS can be integrated to provide an AMIS that can be used to increase nutrient use efficiency, productivity and for environmental monitoring. For most plantations, implementation should proceed using a stepwise approach, beginning with the organization of existing data in agronomy DBMS.

Once data have been organized, GPS and satellite imagery can be used to prepare the base maps required to build a GIS for plantation mapping. A higher level of data analysis is provided when point-by-point data is collected and projected in continuous data variability maps.

As all experienced planters know, computer technology is not a substitute for 'walking the field' but can make field inspections more productive by providing managers with up-to-date information on each field in the plantation that can be referred to during field visits. It is particularly important that precision agriculture technology be introduced in a way that encourages managers to improve performance. If not, it may be seen as a threatening device designed merely to criticize performance.

An investment in equipment and training is required to develop and AMIS. Our experience has shown that a fully integrated AMIS including DBMS, GIS, GPS, and satellite images can be implemented for US$ 5–10 ha^{-1}, equivalent to about 10–20 kg ha^{-1} crude palm oil or 50–100 kg ha^{-1} fruit bunches.

We consider the use of DBMS, GPS, satellite imagery and GIS to be essential tools in the implementation of future precision plantation management. Furthermore, such technology offers an attractive and stimulating working environment for young graduates choosing between a career in industry and the plantation sector.

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Important points for practical planters

1. An agronomic management information system (AMIS) is a basic requirement for plantations wishing to use 'precision' or 'site-specific' approaches to plantation input use.
2. An AMIS comprises:
   - An agronomic database management system (DBMS) for data analysis and storage,
   - Use of global positioning systems (GPS) to collect geo-referenced information,
   - Use of satellite imagery for landscape and canopy analysis and palm counting, and
   - Integration of DBMS and GPS data in a geographic information system (GIS) to produce 'management maps'.
3. GIS mapping and DBMS should be implemented so that a series of reports and management maps can be used to focus costly management time in those areas that have the greatest potential for improvement.
4. Key benefits of precision agriculture
   - Decisions about changes to production inputs can be made based on information rather than subjective judgement.
   - Environmental risks can be reduced by the correct application of inputs such as fertilizer.
   - Input traceability is improved.
   - Data is stored and can be analyzed at a single location and with easy-to-use formats such as maps.
   - Precision agriculture uses decision support tools to help with yield gap analysis, planting material selection, nutrient management, natural resource management.
   - Precision agriculture tools provide a sound basis for ISO 9000 and ISO 14000 certification.
5. Managerial aspects
   - Implementation of AMIS should be carried out in a step-wise process beginning with the implementation of a DBMS to store and analyze plantation agronomic data.
   - AMIS should be properly introduced in the plantation in such a way that management staff recognize its potential to provide useful tools to improve productivity and thus staff performance.
   - Always involve management at all levels in the organisation – there must be buy-in from everyone but senior management influence is important.
   - Slow and steady – methodical systematic approaches work best.
   - There must be early, observable benefits or momentum will be lost.
   - Don't bite off more than you can chew – consolidate improvements before expanding.
   - There should be a 'champion' to introduce any change.
   - Do not underestimate management conservatism and reluctance to change.
   - Calculate costs and benefits.

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