Prospects and constraints to the use of precision farming technology in Cameroon

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ABSTRACT

Farmers and scientists recognize the spatial variability of soil properties on fields. However, due to the complexity of managing this variability, traditional large-scale mechanized farming assumes soils to be spatially uniform. Hence the same amount of agricultural inputs is applied throughout a field resulting in sub-optimum applications. Precision farming seeks to increase the efficiency in the management of agriculture, through the application of variable amounts of inputs to specific areas where and when needed. The expected benefits are; improved yields, and reduced environmental degradation. For mechanized agriculture, it is a high-tech approach, which uses satellite-based sensors, global positioning systems, geographic information systems, computer-linked yield and nutrient monitors, variable rate planters and chemical applicators. Low-tech precision farming based on grid sampling can be applied to un-mechanized plantation crop production, yielding most of the benefits of precision farming obtained from the classical high-tech systems.

This paper reviews the state of the art of precision farming and discusses the constraints and prospects of its use in Cameroon. It concludes that precision farming has the potential of increasing yields and minimising environmental degradation. Though the technology is still in its infancy, research underway suggests that it is set to revolutionize the agricultural engineering industry within the next decade. High-tech precision farming is very unlikely to be of interest to most Cameroonian farmers in the medium term due to the nature of agriculture in the country and the prevailing socio-economic factors. However, low-tech precision farming could be implemented in the short term in plantation crops like tea, coffee, palms, bananas, and rubber. High-tech precision farming can be envisaged in the medium term in plantation crops when the production system is mechanised.

Key words: spatial variability, agricultural inputs, information management, precision farming.

RÉSUMÉ

Les paysans et les chercheurs reconnaissent la variabilité spatiale des propriétés du sol. Toutefois, à cause de la complexité de la gestion de cette variabilité, les méthodes traditionnelles d'agriculture mécanisée à grande échelle supposent une uniformité spatiale des exploitations. Par conséquent, la même quantité d'intrants agricoles est apportée à toutes les parties du champ à cause d'une application non optimale. L'agriculture précise vise à accroître l'efficience dans la gestion des espaces agricoles à travers une application variable d'intrants quand et là où cela est nécessaire. Les résultats attendus de cette technologie sont l'amélioration des récoltes et la limitation de la dégradation de l'environnement. Pour l'agriculture mécanisée, c'est une approche hautement technologique qui intègre des capteurs satelittaires, des systèmes de positionnement, des systèmes d'informations géographiques, des systèmes de prévision des récoltes, des programmeurs d'application de nutriments et des sémoirs à débit variable pour l'application des substances chimiques en fonction des doses requises. Les techniques simples d'agriculture précise basées sur un échantillonnage quadrillé du champ peuvent être appliquées dans des plantations non mécanisées avec autant de succès que les méthodes classiques hautement technologiques.

Cet article fait état de la situation de l'agriculture précise et discute de ses contraintes et perspectives au Cameroun. Il en résulte que les méthodes avancées d'agriculture précise ne pourront que très peu intéresser la plupart des agriculteurs camerounais à moyen terme à cause de la nature de l'agriculture dans ce pays et de certains facteurs socio-économiques. Toutefois, les méthodes simples d'agriculture précise pourront être appliquées à moyen terme dans des plantations de thé, café, bananier, caoutchouc. Les méthodes classiques hautement technologiques d'agriculture précise pourront être envisagées à moyen terme dans des plantations au système de production mécanisé.

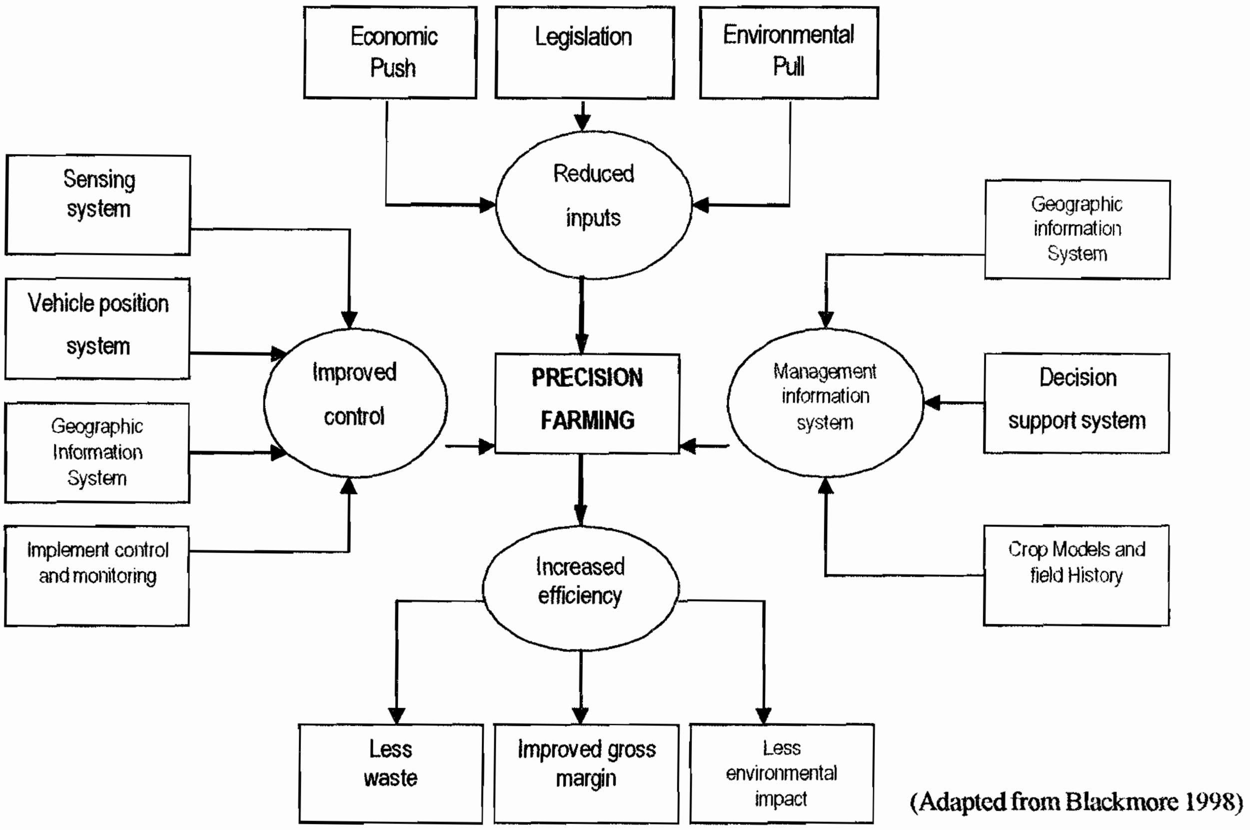
Mots clé : variabilité spatiale, intrants agricoles, technologie de l'information, agriculture précise.

Introduction

Precision farming is the term used to describe a developing technology whose goal is the pursuit of increased efficiency in the management of agriculture, through the application of variable amounts of inputs to specific areas, where and when needed. Precision farming, also called precision agriculture, site specific farming, or soil specific farming is a promising new set of technologies that has generated considerable interest in the agricultural engineering industry over the last decade (Weiss, 1996; Lu et al., 1997; Stafford, 2000). The basis of precision farming is the recognition of spatial variability in soils and crop yields, which has been appreciated by farmers over the centuries. When farm sizes were small and delineated by natural boundaries like soil types and natural drainage channels, farmers treated fields differently in recognition of this variability. With the advent of mechanisation, fields were consolidated to improve field efficiencies of modern agricultural machinery. These consolidations increased the differences in soil type within a single management unit (Stafford et al., 1996). Due to the complexity of managing this variability, traditional large-scale mechanised agriculture has tended to ignore the differences in soil properties on fields. Consequently, fields are considered to be spatially uniform and are given the same application of agricultural inputs throughout. The result is that areas with a smaller need for inputs receive more inputs than required, while portions with a greater need receive insufficient inputs.

Precision farming has developed in the context of the structural transformation and political and environmental scrutiny of modern agriculture. In Europe and North America, the requirements for agricultural production are increasingly in conflict with the requirements imposed by stringent environmental regulations (Bouma, 1999). Due to the increased environmental awareness of the public, the cost of chemical inputs has increased in some countries with the introduction of agro-chemicals tax. Precision farming has developed and continues to expand in order to increase the efficiency and optimise the use of inputs, especially agro-chemicals. In this way, agriculture can address environmental concerns of pollution from mainstream modern agriculture, while retaining its output and productivity advantages (Wolf and Buttel, 1996).

Figure 1 shows the linkages between various elements of precision farming, the forces driving its development and the expected benefits. Two groups of benefits can be derived from precision farming



(Adapted from Blackmore 1998)

Figure 1: **Interactions between various elements of precision farming for mechanised agriculture**

economic and environmental. The economic benefits result from; increase in yields since local under-fertilisation is avoided, reduced expenditures on pesticides from precision spraying, reduced expenditures on fertilisers as local over-application is minimized. The consequence of these is that production is optimised. In addition, there is cost efficient application of seed and water and increased product quality from better timing of the application of fertilisers. For example, Bouma (1999) reported that the timing of fertilizers affects the sugar content of sugar beets and the starch content of potatoes. The potential environmental benefit of precision farming is the reduction in environmental degradation. This results from reduced leaching and reduced risk of pollution of surface and ground water supplies due less wastage from precise application of fertilisers. Secondly, precision application of pesticides reduces the amount of chemicals in the food chain since smaller quantities are used on crop.

The aim of this paper is to review the state of the art of precision farming in general, discuss its potential application in Cameroon agriculture, and the various constraints to the adoption of this technology as well as identify sectors, which have the greatest potential of adopting precision farming.

Components of precision farming

The concept of precision farming was developed for large-scale mechanised agricultural production. Its implementation requires the ability to collect, store, manipulate, analyse, and ultimately act upon a vast amount of spatially localised information relating to the detailed characteristics of a farmer's field (Weiss, 1996). This in turn requires affordable vehicle positioning systems, sensing systems to map soil and crop variability, equipment that can continuously apply variable amounts of inputs and, an information management system. The above results in a high-tech farming system. The desire to increase agricultural efficiency through the application of variable inputs as a function of the needs of the soil and crop can also be applied to un-mechanized large-scale plantation crop production. Here, the application of inputs is carried out manually and so precision farming in this case is based on laboratory analysis of soil samples obtained from grid sampling (Cox and Wardlaw, 1999). This sampling involves dividing the field into blocks and a sample collected from each. The smaller the block size, the more intense the sampling will be and the more accurate the characterization of the spatial variability . Guidelines for farmers to apply varying levels of inputs to different management units can be produced from the laboratory analysis. The precision farming that results from this case could be described as low-tech.

In high-tech or classical precision farming, spatially variable input data are processed to produce spatially variable digital treatment maps. The system therefore, requires information on variability of soil characteristics on the field and the position of equipment on the field in terms of latitude and longitude. The digital treatment maps indicate the amount of input required at various locations on the field. This information must then be communicated to a variable rate applicator for implementation. The key components therefore of a high-tech precision farming system are; positioning, sensing, information management and variable application.

Positioning

The key technology that has driven the development of precision farming is the establishment of satellite-based Global Positioning System (GPS). This makes it possible to continuously determine machinery positions on a field accurately in terms of the latitude and longitude (Bradley et al., 1999; Stafford, 2000). A GPS receiver mounted on a farm vehicle captures signals from a constellation of satellites and computes the distance between the satellite and the receiver. If four or more satellite signals are received, the GPS receiver can determine the 3-dimentional position of a location on earth. The GPS was initially developed for use by the United States military. For civilian applications, the accuracy of the system was reduced by deliberately introducing errors in the signals from satellites to avoid the military of other countries using the system.

The GPS can be used in one of two modes; single or differential. In the single mode, one receiver collects information from as many satellites as possible and processes it into positions on a field. This is the cheaper method, but the accuracy is currently limited to about 15 m of the true position due to the deliberate signal errors from satellites. In the differential mode, two receivers are used; one stationary and the other mobile on a farm vehicle. Due to the introduced errors in the signals received , the stationary receiver appears to move. This error is transmitted to the mobile receiver and used to improve the positional accuracy. Commercially available hand-held GPS receivers now cost about US$160 with sub-metre accuracy claimed in the differential mode with corrections (Stafford, 2000). Various developments underway suggest that centimetre accuracy will be available for precision farming before long (Goad, 1996). Figure 2 shows a sketch of the GPS in the differential mode.

Sensing systems

The implementation of precision farming requires the collection of a lot of geographically referenced variables of the crop, soil and the environment. Ideally, this information should be available shortly after collection (real-time) for use in decision-making and should be

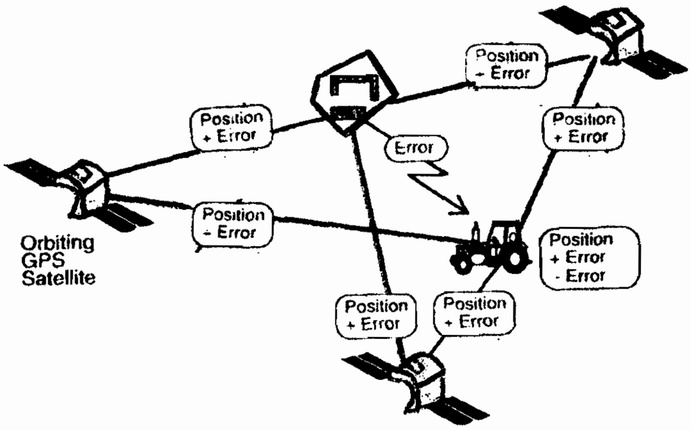


Figure 2: **A Global Positioning System used in differential mode**

affordable. The data collection should preferably be by remote sensors. However, the only commercially available systems today are yield mapping and soil conductivity mapping systems (Stafford, 2000). Satellite data are available but not in a form suitable or available at the times of critical decision-making (Bradley et al., 1999; Stafford, 2000). Soil and crop data such as soil moisture and acidity, crop vigour and disease presence can presently be obtained only through expensive manual sampling and analysis. Remotely sensed satellite data can be obtained to indicate crop stress and yield potential but not in a timely and cost effective manner (Steven, 1993, Schepers et al., 1996).

Yield mapping is often the first step in implementing precision farming as it enables farm managers to visualise the extent of the variability of yields resulting from differences in soil characteristics. (Lu et al., 1997; Lark & Wheeler, 2000). However, there are still many problems in relating one year's yield to the next due to seasonal variability. Because of the ease with which yield data can be obtained, techniques have been developed to interpret the data and relate it to the variability of inputs economically (Lark & Stafford, 1997; Lark & Wheeler, 2000).

It is difficult to infer the spatially variable treatment to apply to crops, from the variability of soil properties because of the complex interactions between the soil and crop growth. However, this information is useful in determining the factors limiting yields such as nutrient deficiencies. Lund et al., (1999) concluded that mapping electrical conductivity can be a good surrogate measurement for variables like soil type and moisture content which are more difficult to measure. Commercially available sensors mounted on farm vehicles are now available to map electrical conductivity.

Information management systems

GPS signals and the associated measurements of the spatial variability of different factors, produce a lot of data. Each variable can be separately stored digitally and referred to as an overlay. The management, analysis and display of geo-referenced data can be best handled by a computer software package called Geographic Information System (GIS). The software can accept, organise, statistically analyse and display diverse types of spatial data that are digitally referenced to a common co-ordinate system (Blackmore, 1994). Combining a number of overlays can produce new data sets. Examples of overlays are; soil type, topography, depth of seedbed, moisture content, crop yield, and land cover. Since all the data are stored digitally, they can be easily modified, copied and reproduced. Using the digital data, derived maps can be obtained by combining sections of existing maps that meet certain conditions. For example erosion potential can be defined in terms of land having a certain slope and a given amount of crop cover. A GIS enables farm managers to determine the best agronomic recommendations and the required levels of input to apply to different parts of a field. The GIS has been combined with crop simulation models and decision support systems to produce powerful management tools. The output of all these is a spatially variable treatment map which can then be stored on a disk for use by on board computers in farm vehicles.

Precise application

Once a spatially variable treatment or input map has been produced, it has to be accurately executed by a variable rate applicator. Conventional applicators of seeds, fertilisers and pesticides have been modified with the inclusion of a GPS and programmable controllers to apply inputs at variable rates. A GPS receiver, mounted on the farm vehicle provides information of the position on the field. This is used by on board computers together with the treatment map to send information in real-time to controllers connected to the variable rate applicators to apply varying amounts of inputs to different sites as prescribed by the treatment map.

Further research

Implementation of precision farming has so far utilised existing field machinery unto which controllers and GPS were added to obtain variable rate applicators. This approach has limited precision compared to that presently available in sensing and positioning systems. There is therefore a need to develop more accurate machines for the precise application of inputs.

The technology for determining the presence of weeds as the tractor moves along so that the rate of application of pesticides can be varied is still not quite developed. Sensors are required to determine the presence as well as the type of weeds. Satellite based sensors are currently used for obtaining spatially variable data. However, this information is often not available in real-time. There is therefore a need to develop sensing systems for obtaining such information in real time and at an affordable cost for use in precision farming. Moulin et al., (1998) reported that systems were under development that had the potential of eliminating the drawbacks of remotely sensed data from satellites.

The crop is the best sensor of its own environment. Therefore systems based on the condition of crops can provide information on the required spatially variable inputs (Legg & Stafford, 1998). The information is obtained mainly from the spectral reflectance characteristics of the crop from satellite or field vehicles. Work still has to be done to distinguish the characteristics of crops or weeds, and to determine the exact cause of changes in the spectral characteristics due to plant stress.

Practical applications

Precision farming often starts with the production of yield maps. Most applications of precision farming are currently limited to crops, which can be harvested by combine harvesters. This is because, many of them have been equipped with GPS and sensors added to weigh the harvested crop continuously to produce a yield map. For crops harvested by combine harvesters, the traditional practice is to set the seed rates during planting with a wide margin of error. This ensures that parts of the field where there might be difficulties with establishment due to a shallow seedbed, low moisture content etc will have an adequate population. Hence the density of established plants usually exceeds the optimum for most field crops. This results in unnecessary expenditure on seeds, and an increased risk of lodging (Easson et al., 1993). Precision farming technology has therefore been applied to planters to vary the seeding rate continuously during planting as a function of suitability of the seedbed.

Precision farming is usually considered for fertilizers like nitrogen where the yield response is large. However, the response is difficult to predict as the variability in fields is often a combination of several factors; variability in the previous application of nitrogen, soil organic matter content and soil microbial activity. The amount to be applied at any given point on the field can be determined from laboratory analysis of soil samples obtained from grid sampling. This approach is slow and expensive and is therefore not often used commercially. However, Blackmer and White (1998) found that for some conditions, spatially variable applications based on intensive sampling are economic.

For the application rate of herbicides to be varied as a function of the amount of weeds on a field, a map indicating the presence of weeds needs to be produced. The current practical method for determining the presence of weeds is to map weed patches with a GPS equipped combine harvester during harvesting. This is done by visual observation, and noting the location of the weed patch. This approach is possible for weeds unlikely to be controlled during crop establishment from cultivation and pre-emergent spraying. Seeds from such weeds tend to produce areas of high infestation. Rew et al., (1996) showed that savings in herbicides of up to US$ 20 /ha could be attained for some weeds when precision application was implemented. Precision agriculture has also been applied to mobile sprinkler irrigation systems to apply water, as a function of the plant needs and the variability of the soil.

Precision farming has been applied to a number of areas like fertilizer and pesticide application, planting as a function of the suitability of the seedbed quality, and to irrigation with mobile sprinklers. The biggest handicap to its widespread use is the availability of sensors that can provide real-time data of the crop, soil and climatic variables, which can be used for the production of treatment maps. Considerable research and development is currently underway to develop sensors and more accurate implement control for precise application of inputs. This technology has the potential of increasing the efficiency in the management of agriculture, leading to increased yields and minimizing environmental degradation. The technology is still in its infancy but research in this area suggests that it is set to revolutionize the agricultural engineering industry within the next decade.

Constraints and potentials of precision farming in Cameroon

Traditional agricultural production systems have typically involved the employment of agro-ecological, biological and genetic diversity as management tools (Wolf and Buttel, 1996). This approach accomplishes goals such as food sufficiency and minimisation of risks from weather and disease variables. Traditional peasant production systems, which dominated agriculture in developed countries until the late nineteenth century, are still the dominant systems of production in Cameroon and many other developing countries.

Precision farming combines traditional large-scale tractor-based technology with 21st century information technology. Hence, it requires higher capital intensity and is characterised by economies of scale. It requires a good degree of competence in the use of computers by farmers. The above characteristics do not reflect the agricultural system practised by most farmers in Cameroon, where the level of mechanisation is still very low. The FAO (1995) reported that in 1994 there were only about 500 agricultural tractors in service in Cameroon for a farming population of about 7.5 million. The average size of holdings was estimated at about 1 ha with most farmers using hand-tool technology. Hence the resource poor farmers in Cameroon who constitute the majority, and most of whom are illiterate, are very unlikely to adopt high-tech precision farming technologies.

In addition, high-tech precision farming is inappropriate in this farming system because the farmers already practice site-specific farming. The small sizes of farms and the familiarity of the farmers with the variability of soil properties enables them to recognise which fields are suitable for different crops or where yields are higher. They therefore vary inputs in consequence. For example, in a study in Niger, Lamers and Feil (1995) found that farmers explained spatial variability of yields in their fields in terms of differences in soil types, soil fertility and degradation as well as their cultivation and management practices. It was also found that they counteract spatial variability in yield by within-field fallow, spot application of manure and by exploiting the micro-environmental differences around some species of trees and shrubs.

Some agricultural sectors in Cameroon have the conditions that make high-tech precision farming feasible if their operations are mechanized. Managers of plantation crops like tea, coffee, palms, bananas etc, usually have the competence, capital and the economies of scale suitable for precision farming. With globalisation, owners of plantations are likely to use precision farming technology to reduce their production costs so as to remain competitive in the world market. However, the cultivation of plantation crops is currently carried out manually. Operations like planting, fertiliser application and harvesting are usually carried out by hand. Grid sampling (Cox and Wardlaw, 1999) can be used to determine manageable units for the application of inputs and also for the production of yield maps. Colour codes can be used for crops on different blocks or management units to indicate the amount of inputs required. The inputs can then be manually applied as before. For example, in tea plantations, the standard 0.25 ha block could be initially defined as a management unit on which inputs could be varied.

Yield maps can also be easily produced without the need for a GPS for plantation crops. The division of the field into blocks and the recording of harvest from each block can be easily carried out. Such maps can be used to define potential management units using approaches developed for combinable crops (Stafford et al., 1999).

Plantation crops often use aerial application of pesticides, which offers a good opportunity for the application of precision farming. Remote sensing could be used to detect problem areas caused by pathogens, so that the timing and application of fungicides can be optimised. Studies in Japan have indicated that incipient crop damage can be detected using near-infrared narrow band sensors (Srinivasan, 1999). This can be obtained from satellite imagery and a spatially variable treatment map produced for use by aircrafts during the application of pesticides.

The irrigation of plantation crops like bananas constitutes a major cost item. This is another area to which low-tech precision farming can be applied. Solid set systems are often used with valves opened manually to irrigate different areas of a field. The variability of available water capacity could be mapped from grid sampling and a water budget kept to determine the spatially variable cumulative soil moisture deficit. Irrigation can therefore be scheduled by varying the timing and amounts of water as a function of the soil moisture deficit.

Conclusions

Precision farming has the potential of increasing the efficiency in the management of agriculture leading to increased yields and minimising environmental degradation. The technology is still in its infancy but research underway suggests that it is set to revolutionize the agricultural engineering industry within the next decade.

Resource poor farmers in Cameroon are presently practising low-tech site-specific farming due to the intimate knowledge of their smallholdings. Application of high-tech precision farming based on intense capital and information technology is therefore neither appropriate nor needed. Plantation crops however owned by the state or agri-businesses offer opportunities for the application of precision farming due to their economies of scale, availability of resources and skills and the need to remain competitive in the world market. Since the production system is essentially manual, low-tech precision farming can be applied in the short term starting with the determination of yield maps from grid sampling. This should be followed by the production of treatment maps from the analysis of soil samples obtained from grid sampling especially for fertilizer and irrigation water application. In the medium to long term, high-tech precision farming can be introduced in mechanized large-scale farms.

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