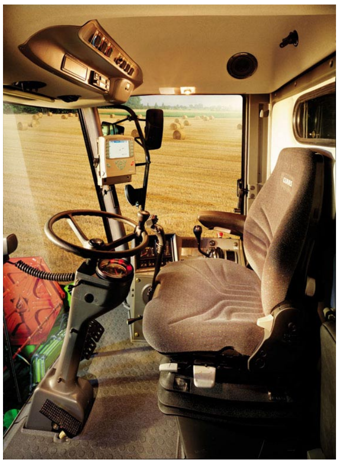
PRECISION FARMING

IN

SOUTH AFRICA



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CONTENTS

Page No.

FIGURES

Page No.

TABLES

Page No.

1. INTRODUCTION

Precision Farming is a process whereby a large field is divided into a finite number of sub-fields, allowing variation of inputs in accordance with the data gathered. Ideally this will allow maximisation of return on investment, whilst minimising the associated risks and environmental damage. The German term for precision farming, 'Teilflächenwirtschaft' (Profi, 1998) is far more descriptive of this process.

Precision Farming has essentially four defined steps, these are:

- Gathering of information on the sub-field;
- Analysis of that information;
- Taking decisions based on the analysed information;
- Implementation of these decisions

Precision Farming is about to change the face of agriculture, as we know it today. Precision Farming has been developed mainly in Europe (Moore 1998a). It has, however, been adopted by North American Farmers in far greater numbers than in any other part of the world. Various sources (Starck, 1998) show that probably around 90% of all Precision Farming Systems operate in the US and Canada.

Precision Farming is by far the most exciting new agricultural technology developed during past decade, and although technology transfer is especially difficult in agriculture (Rüsch, 1993) for a number of reasons, this technology has survived its initial stages of implementation.

In this report, the author will show how Precision Farming was developed, initially using Yield Mapping as primary data source, the components of Precision Farming Systems, some results of trials in South Africa, introduce Computer Aided Farming Systems (CAFS) and their inputs. The author will subsequently propose a strategy on how to implement a Precision Farming System successfully under South African conditions. Finally, the author will express an opinion on how the future of these systems is likely to look, taking his practical experience over some 3 000ha into account, as well as recent developments in the IT industry.

1.1 The Development of Precision Farming

Precision farming was developed over the past decade, having it origin in Europe. As often the case with new technologies, this practise was taken up in the US and developed at great pace.

1.1.1 Background Development

Over the past 30 or so years, Agricultural Machinery has been developed to high technical standards. In summary the following was achieved:

- Tractors have been developed where an operator can work all day in a comfortable environment;
- Application equipment such as sprayers and spreaders have developed to achieve uniform application of fertiliser, and plant protection chemicals;
- Combines have been developed to harvest under virtually any conditions, with very low losses (sub 1% is an accepted Norm (Claas, 1998)) of the crop.

It must be noted that the development was mainly to achieve uniformity of some kind, be it uniformity of application (sprayers and spreaders), uniformity of working depth (drawn implements) or uniformity of tractive effort (3-point mounted implements).

As a result of this technical evolution, and the demand for higher efficiencies to stay competitive, has lead to a gradual increase in the average size of equipment sold. At the same time a large consolidation of farms took place, both in and outside South Africa, giving rise to an increase in farm’s size, and ultimately field size.

This has lead in many cases to fields being thrown together as one field, although the potential of the separate fields differed vastly (Moore, 1998). In many instances, especially in South Africa, with its marginal agricultural potential, fields were often extended to include areas with little potential for cash cropping (Lourens A, 1999)

Pressure from organised environmental groups, especially in Europe, has certainly contributed to an increased environmental awareness of the general public, and also farmers. The author has observed that South African farmers have also become more environmentally conscious (Tom Bourke 1999, NAMPO 1998).

1.1.2 Agricultural Background

Photosynthesis is the basic process upon which all green plant production rests. Carbon dioxide and water are converted in the presence of light energy into glucose and oxygen in plant chlorophyll. To date there is little evidence that the total biological yield has increased for modern cereal varieties (Evans, 1975). Economic yield has however increased, mainly due to two reasons:

- Better varieties;
- Better husbandry.

There are a number of factors, which influence crop production, and although not the theme of this report, some basic background has to be given. The factors, and how they influence crop production, as well as other interrelationships are as given in figure 1.

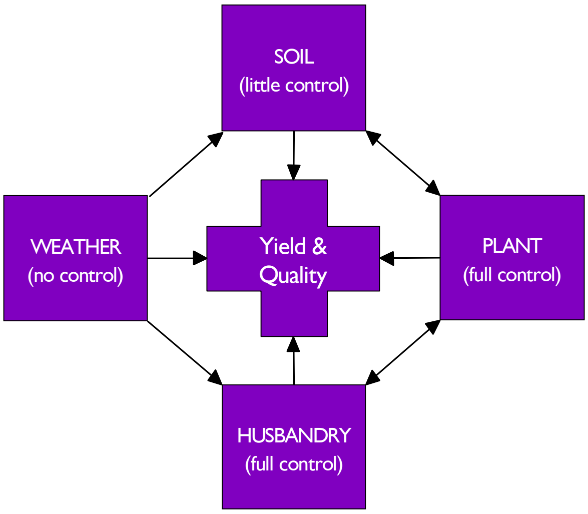

Fig. 1: Factors affecting yield and quality

A short summary of some effects of the factors is as listed below:

- Weather (no control);
  - We all know what influence weather can have on crops, and yield in climatic conditions such as in South Africa;
- Soil (little or no control);
  - Hutton vs. Katspruit;
  - Inherent fertility (soil structure, water logging…);
  - Achieved fertility (fertilisers, humus content…);
- Husbandry (full control);
  - Selection of fertilisers, insecticides, herbicides;
  - Timing of application;
  - Efficiency of application;
- Plant (full control);
  - Choice of crop (maize, sunflowers…);
  - Variety (more or less suitable to the locality);
  - Plant population (row spacing, intra row spacing…).

Farmers, when planning the crops for the next season consider all of the above factors.

1.1.3 Initial Precision Farming Work

During the early 1980's (Moore 1998), Droningborg in Denmark did initial work to determine if difference in yield across a field existed, and how big these differences were.

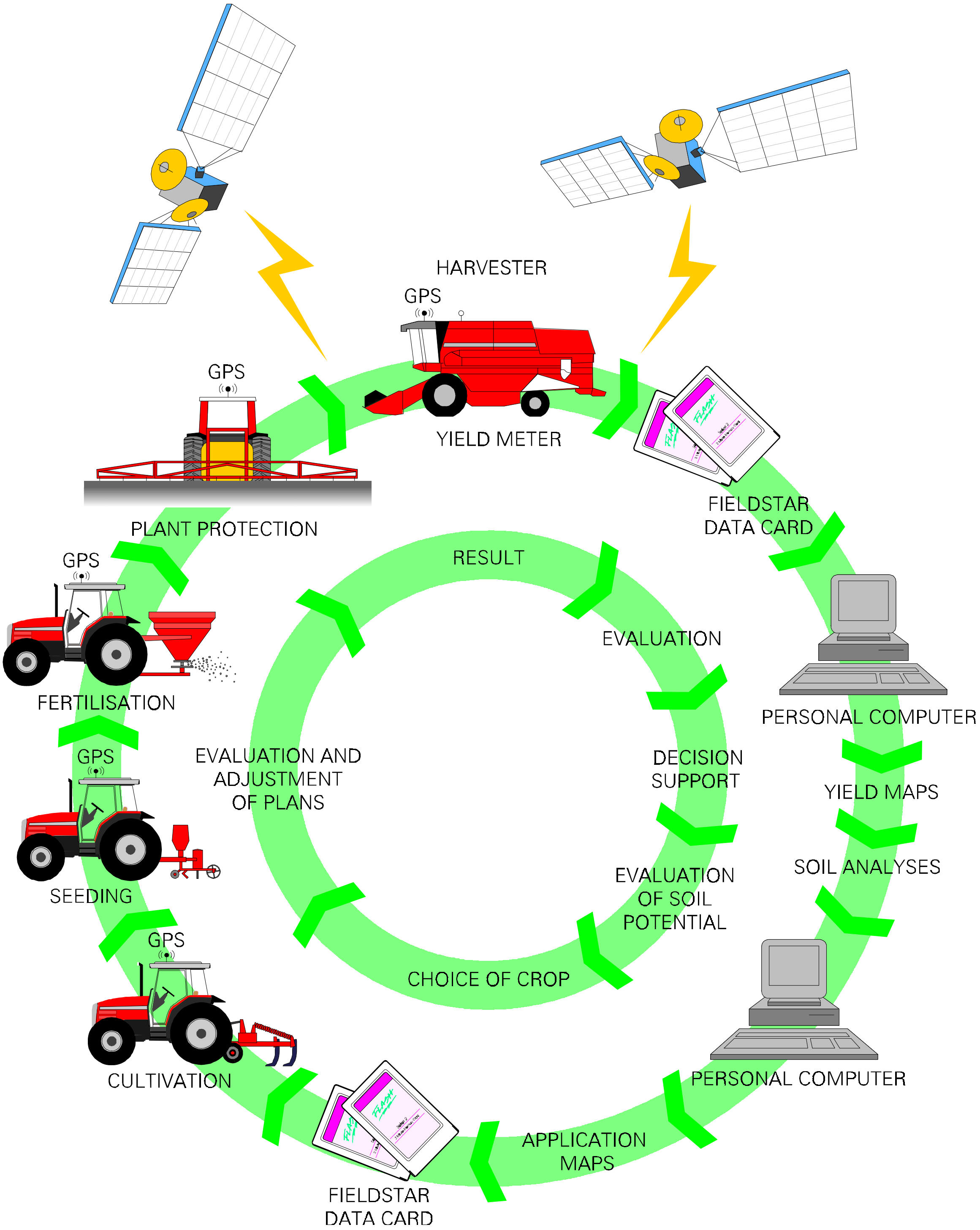

Fig.2: Precision farming circle

The first yield map, which was subdivided into 69 sub-fields, showed variations of yields between 4 and 6.5t/ha. A copy of this map is attached in Appendix A. This first map was very encouraging, as it was generally believed in Europe that the yield differences within a field would be fairly small. However, based on the average yield of some 5.3t/ha in this trial, the recorded differences were ± 20%.

During this phase, slow progress was made with the development of the system, largely due to the lack of a precise geo-referenced locating system. Early photos (a copy is attached in Appendix B) during this phase show typical locating equipment, based on triangulation of beacons erected around the test fields.

During this time much of the foundations of the Precision Farming Systems in their present state of development were laid.

1.2 The Precision Farming Circle

The processes involved in Precision Farming are often (Massey Ferguson, 1996; Claas, undated) represented as in figure 2. The inner circle represents the action to be done, whilst the outer circle gives a graphical representation of the actions involved. These actions can best be described as follows:

1.2.1 Result (Gathering of Information)

In this part of the circle results are gathered. Although both Massey Ferguson, and Claas (and some others) only tend to show a yield map here, especially Massey Ferguson (Moore, 1998) has done work on the mapping of other results. Generally data for value maps (where a value map is any map showing a useful data set) can be collected either automatically (such as a yield map) or manual (including semi-manual) such as a soil nutrient status map. Apart from soil samples, it is generally not worth the effort to collect data, which is not collected automatically.

Usually soil samples are collected manually, and the number of data points per surface area is therefore lower. Lourens U (1999) and the author discussed a practical number of soils samples, and found that costs will probably prohibit more than 1 sample per 2 ha, with 1 sample per 5 ha a possibility in areas where fairly uniform soils occur. However research into the grid size for soil samples by Clay et al (undated) yields the following observation:

"*In developing a soil sampling protocols, it is important to understand that different objectives have different requirements. For research purposes grid points need to be relatively close together in order to define the spatial variable. However, for making fertilizer spread maps a coarse grid may provide the information required to improve profitability. Sampling protocols should be considered separately from fertilization strategies, because the cost of variable rate equipment is substantial more than fixed rate equipment. In this paper, the economic analysis* *showed that the investment in using variable rate equipment was greater than the expected economic return in some treatments.*

Understanding field nutrient variability provided the information that could be used to improve profitability. The highest profits were estimated when samples were collected from a 90 m grid or when composite samples were collected from each soil series and the old feedlot was treated as a separate management unit. The relationship between profitability and amount of information collected was the direct result of the exponential relationship between cost of obtaining information and the amount of information collected following, while the relationship between the profitability and amount of information collected followed a curve where the net return increased with the amount of information collected up to a maximum value. It is important to note that this analysis did not consider environmental considerations."

The above was as result of research done in the US, where generally profitability of farms seems to be higher, and would confirm the views expressed above.

Once the physical properties of the soils have been established, soil sampling becomes limited to collecting chemical properties, thus reducing the amount of soil per sample required.

In the fully automatic mode, the number of samples per hectare can be very high (± 600 / ha), as shown on a FIELDSTAR™ raw data map in Appendix C. The number of points can vary significantly with the following factors:

- Effective width of the track (cutter bar) (wider = less points /ha);
- Travelling speed (faster = less points /ha);
- System specific settings of the manufacturer.

The author found that the Claas AgroCom system used for his trials gathered between 84 points/ha in the Swellendam area (low yields, 17m swath in canola, First Yieldmap), 144 points in low-yielding dry land conditions (Land 5) and 170 points / ha (Pivot 3), where for large parts of the field only alternative rows were mapped. The maximum number of points collected were 215 points/ha (Reid, 6,1734ha and Le Roux, 22.3474ha) with two different combines (Lexion 460 & 450 respectively) and two different cutter bars (7.5m & 9,0m respectively). The raw data maps are attached in Appendix C. This is significantly lower than the number collected by the FIELDSTAR™ system, but the results may not be directly comparable, due to largely different circumstances.

At present most efforts in the collection of information is centred on the collection of yield maps (Moore 1998) and the associated soil data (Muller, 1999). Both Massey Ferguson (Moore, 1998) and Claas (Meyer, 1999) are developing systems for the collection of data of forage yield (with forage harvesters), potatoes (with potato harvesters) and sugar cane yield (with cane harvesters). Some examples are attached in Appendix D. Massey Ferguson (Moore, 1998) is also developing a system where draft forces are measured (using the outputs from the Electronic Linkage Control) and converted to map the effort required to work a particular sub-field. Amazone (Amazone, 1997) has developed a system, which varies the quantity of fertiliser dependent on the vigorousness of growth.

It appears that a lot of different data sets can technically be collected, and if geo-referenced, can also be mapped. Some possible sets are listed below:

- Yield (mainly of cash crops, but also forage and sugar cane);
- Vigorousness of growth (either by satellite or during plant protection measures);
- Soil type;
- Soil nutrient status for a variety of macro and micro nutrients;
- Penetrometer readings;
- Disease status of the soil (nematodes etc.);
- Soil resistance to cultivation;
- Heat uptake of the soil in spring (soil temperature);

The ideal situation would be where every trip undertaken over a field, yields a useful data set of some kind, i.e. a value map of some kind.

1.2.2 Evaluation (Analysis of Information, including Soil)

During this step the gathered data is evaluated to assess whether the data is a long-term trend or not. Moore (1998) shows that using local knowledge as observed during the year can save considerable time. The main aim of the evaluation should be to assess whether all data is consistent, and if not, find possible errors in the system, which may have caused inconsistencies.

It is generally thought (Claas, undated & Massey Ferguson 1996) that around 3 yield maps are necessary to start implementing the system. This is because, in the absence of additional, supplementary information at least 3 yield maps are required to ascertain if the yield in a particular sub-field is consistent in the long-term.

It seems generally in a country such as South Africa, where the inter-seasonal variability is much greater than in Europe, or certain parts of North America; more yield-maps are required to find long-term trends.

For each and every value map, the process as depicted in figure 3 needs to be followed to ascertain which parts (of the map) reflect long-term trend, and which have been influenced by seasonal problems, such as water logging, or local disease spots. It is quite important to note that Moore (1998) suggests that one should evaluate physical soil properties prior to examining chemical properties. This is suggested as it was found in UK that more often than not, physical problems gave rise to the reduction in yield for a particular sub-field. Given that we are 'Farming with Water' (Lourens A, 1998) in South Africa where available water is often a defining factor in the total yield, this may also here prove to be the right approach.

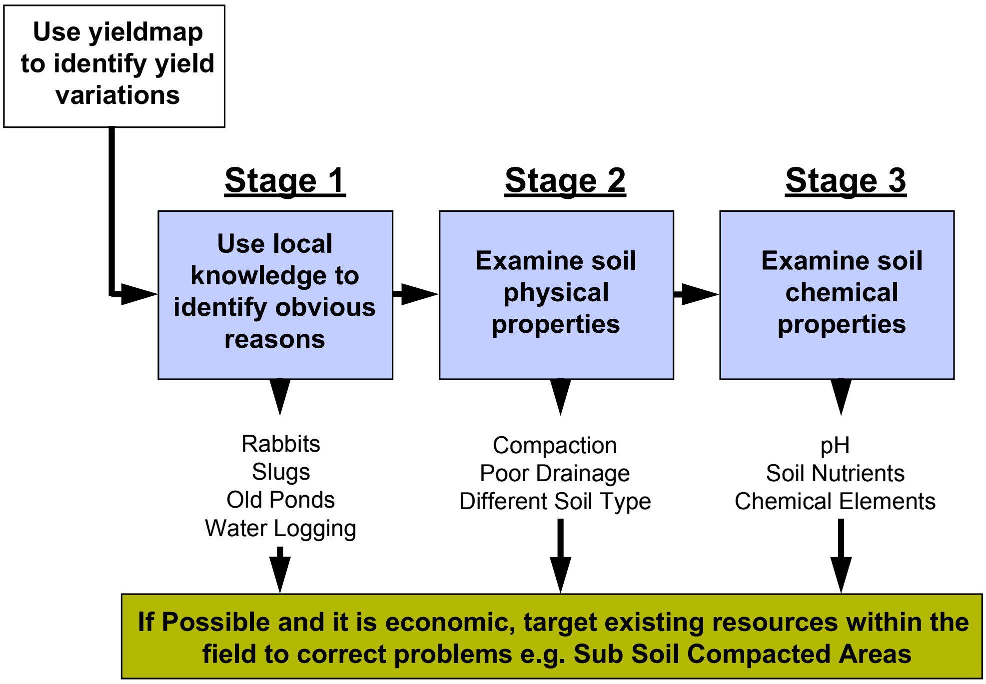

Fig. 3: Strategy to evaluate reasons for yield variations

As it becomes obvious that local knowledge play a large role in evaluating a value map, it has proven useful (Moore, 1998) to record all observations made during a particular growing season. A simple notebook for each operator is all that is required.

It is important to keep the economics in mind when trying to solve identified problems, as it is, however nice, simply not viable to remove all factors constraining yield for a sub-field. A quick calculation to reveal the Internal Rate of Return is all that is required.

Moore (1998) also suggests that long-term trends can be established faster by making use of satellite images to establish parts of the fields that are showing their long-term trends. Bornman (1998) backs these observations. Both propose the use of either satellite or aerial imagery to identify the distribution of growth vigorousness across a field, and then create a difference map with the yield map, thus identifying areas where a high vigorousness resulted in high yield, and a low vigorousness resulted in low yield. All other combinations of vigorousness and yield would be atypical, and therefore not represent a long-term trend. A typical example of a difference map is shown in Appendix E.

1.2.3 Decision Support (Decision based on Information)

A decision support system will enable the farmer to quickly evaluate a host of different scenarios regarding most factors influencing his farming operation, and hence the way he has to treat his crops. Initially these systems will be fairly simple, barely allowing more than evaluating the value map. Typically these ‘entry level’ systems are delivered with the yield monitor, and effectively provide the means to display the raw data (as per Appendix C), determine the field size, and represent the yield in a typical graphic format (as per Appendix F). The user may also associate certain application rates (see Appendix G) for certain yields (or other values for other value maps) and export these to application equipment.

As the data available to the farmer becomes more, and more complex (such as tractive effort maps), these entry-level systems will be hardly sufficient to satisfy the requirements. As soon as more than one value map has to be evaluated at once, these entry level systems will be replaced with a more advanced system allowing the user to evaluate more than one value map against a host of varying requirements at once. Some of these systems seem to be custom written for the purpose, but at least in one case so-called ‘add-on’ modules were written for a commercially available Geographic Information System (GIS). During the trials, the author used the entry-level software from Claas, and whilst fully adequate for the purpose to display and graphically present data, this software did not allow the simultaneous evaluation of a number of overlaid maps.

As a decision support system, if used to its full potential will enhance the effectiveness of Precision Farming significantly. Figure 4 (adapted from Moore, 1998) schematically represents the actions that need to be taken to add value. As the functions required typically would require access to other agricultural decision support systems used on the farm, it seems logical that a system compatible with these is used. It seems that Claas, through its AgroCom division has for that reason acquired a software company in Germany known for its farm management software.

At least some farmers in South Africa (Osborne, 1999; Lourens A, 1999) have indicated that they are not so much interested in operating the systems, but would prefer to just have access to the end result. This view is shared by Senwes, in their Precision Farming Centre. (Helm, 1998)

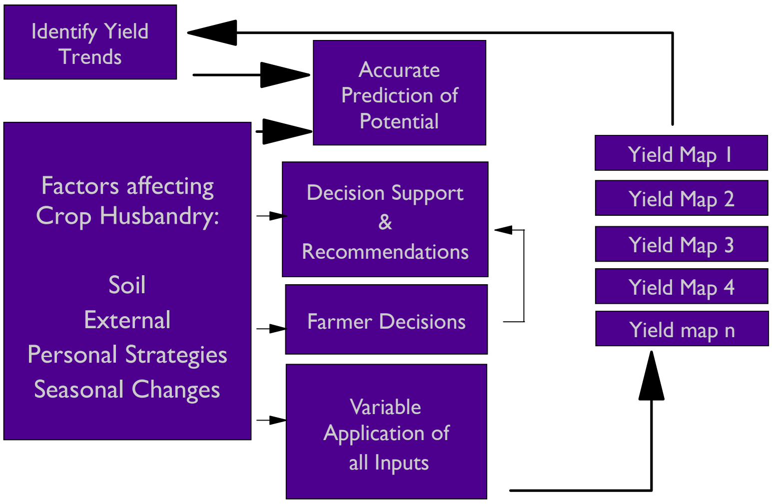

Fig. 4: Flow diagram for decision support

1.2.4 Evaluation and Adjustment of Plans (Implementation)

Based on the output of the decision support system, the farmer has a proposed schedule for planting, fertilizing and plant protecting for the upcoming season. This schedule is defined by his personal strategies, and an average season. Hardly any season in South Africa is average, and as certain personal strategies are influenced by events worldwide, the farmer may need to adapt this schedule during the season. It may be necessary for example to reduce the planned fertiliser rate, as the season is drier than an average one. Especially during this phase, as decision support system can be valuable, as specific ‘treatment thresholds’ can be defined and crops can then be treated accordingly.

Once the farmer has completed this last step, he can gather the next set of results.

2. TECHNICAL COMPONENTS OF A PRECISION FARMING SYSTEM

Precision farming, as defined above, has four main steps. For each of these steps a variety of different technical components are needed. As seen above (section 1) a large amount of data needs to be transferred between a number of different components and machines. To facilitate this flow of data, a working implementation of DIN 9684 (Marquering, 1997) is used by some of the main players in the field. Although apparently both John Deere and Case initially used propriety systems (with interaction possible only with other systems of the same manufacturer), most large manufacturers now subscribe to the above Code. A typical advertisement in this regard is attached in Appendix H. Essentially there are data collection systems, and application systems. The components needed for each of these systems are discussed below:

2.1 Gathering of Information (Data Collection)

As shown in 1.2.1 above, a large variety of information can be gathered. Although it may seem that a large variety of complex components are required, all systems are built of the following basic components:

- A main unit. This unit usually also houses the user interfaces (display and keyboard)
- A job computer (one for the carrier (tractor, combine), one on the implement / measuring device)
- A positioning system. This may, during data collection be an uncorrected GPS system, but with application it must be a corrected GPS system (DGPS). Positioning systems are discussed in more detail in section 3.

Figure 5 illustrates the typical layout of the Claas LEM based system (Claas, 1997). This system is used as an example to illustrate the different components, and their interactions. Most data collection systems will follow similar arrangements, but may combine the functions in a different way.

In this figure two main units are shown, the CEBIS computer (part of the combine electronics on a select range of combines) and the AgroCom Terminal (ACT) for retrofit purposes. Not shown in the figure is the job computer for the combine (see Appendix I). This module forms part of the combine electronics when the CEBIS system is used.

The following functions are allocated to each part of the system:

2.1.1 Job Computer (Measuring Device)

This unit controls the light-beam based quantimeter, as well as the moisture sensor. Its output to the main unit is volume, as well as moisture content. The light-beam based

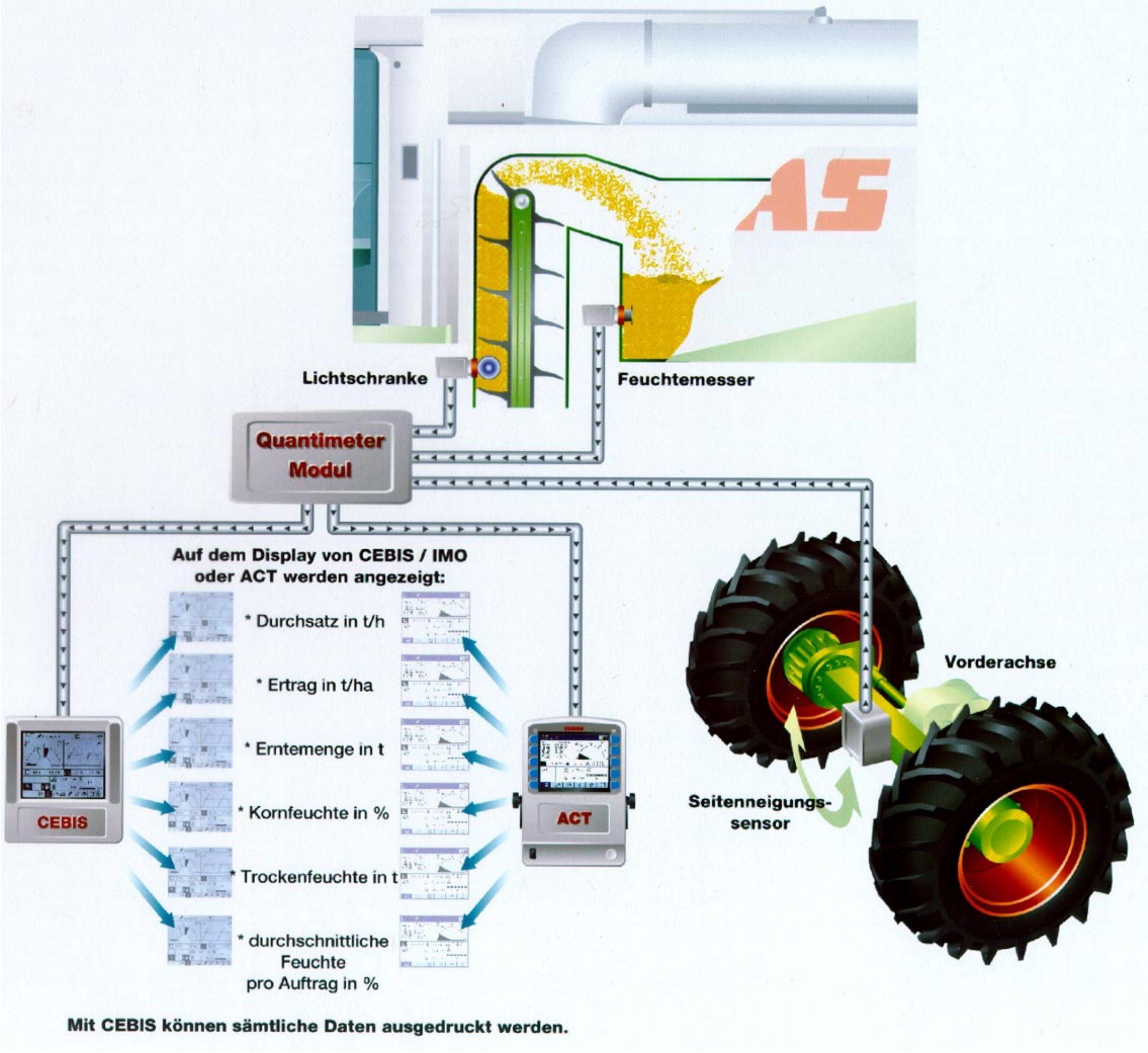

Fig.5: Layout of Claas LEM quantimeter

quantimeter measures the volume of clean grain by measuring the fraction of light transmitted through the clean grain elevator. A smaller fraction indicates a larger volume of clean grain. This volume has to be corrected for inclination about the two main axes of the combine, to prevent faulty reading in hilly areas. To perform its functions, it can store the following core data:

- Dimensional data on the elevator, in which it is installed. This data is preloaded via the main unit as default values, and these worked well for retrofit use on Claas combines. When a test unit was installed on a CASE Axial Flow combine, these preloaded factors caused error of up to 55% (Muller & Rüsch, 1998);
- Calibration data for the clean grains elevator. This data setting is essentially a ‘tare’ setting for the clean grains elevator, as well as the frequency of the passing paddles, and should be calibrated once a day;
- Calibration data for the incline meter. Initially Claas used only one meter to measure the sideways inclination of the combine, but with the CEBIS II this was changed to two meters;

- Calibration data for the moisture sensor. This is sensor dependant, and cannot be adjusted.

2.1.2 Job Computer (Tractor or Combine)

This job computer has to provide tractor or combine related data to the main unit, and effectively make it available to the other job computers via the Data Bus (see figure 6). The flowing data could be provided:

- True travelling speed, measured by radar (if measured);
- Wheel speed;
- Slip percentage (if measured);
- ELC Data (such as position, draft forces…);
- Engine speed;
- Engine load as percentage (only a few tractors can make this data available at present, this requires full electronic control of the fuel supply);
- PTO Speed;
- Header on / off (combine);
- Header position (combine).

Similar to the job computer under 2.1.1, this job computer will also store a host of data required for calibration purposes, for example the number of impulses per revolution of the PTO shaft, the number of impulses per 100m for wheel speed.

Job computers are designed for the specific requirements of the particular machine they control or provide data from, and are not interchangeable. However, they provide and accept data in a standardised format (to the working implementation of DIN 9684) across the data bus of the system.

2.1.3 Main Unit

The main unit is used to interact with the user, and to display the current status of the system. This may be a touch-screen unit as the FIELDSTAR™ unit, or a unit such as the AcroCom Terminal (ACT). These units are usually built around an industrial type computer, and may incorporate an 8 channel GPS card in combination with RDS correction (ACT) or rely on an external DGPS system (ACT and FIELDSTAR™). The unit also connects to a data bus, to transfer and accept data in a predetermined format. Data can also be transferred to a chip card (usually a PCMCIA type card) for use in an office computer and interfacing with the decision support system

2.2 Application Systems (Implementation of Decisions)

After an implementation schedule has been drawn up, the inputs are applied according to the potential, which has been estimated using the decision support system, based on previous yield maps, personal strategies, and the planned crops for the next season.

Fig. 6: Typical layout of application controls

All implementation is done in a similar way, where the variable input is defined on a map; this map is then transferred via a chip card to the main unit. The software in the main unit, once in the field, then gets the actual position from the DGPS positioning system, looks up the value to be applied to that particular sub-field, and feeds the value, as well as other core data such as speed (both true – if available – and wheel speed) along the data bus to the job computer on the implement. Here the job computer's function is to apply the correct amount of input. Figure 6 shows the typical layout and flow of information. Shown here is one possible configuration of the FIELDSTAR™ unit, where the DGPS receiver is connected to the job computer of the tractor. A typical system would, therefore have, similar to the data collection systems, have the following components:

- The main unit;
- A job computer for the tractor;
- A job computer for an implement.

The first two units are the same as for the data collection systems (Massey Ferguson & Claas ACT), but may also be different units (Claas CEBIS & ACT or John Deere and Case). It depends to a large extent on the chosen supplier. At present it seems the only truly multi-functional units as foreseen under DIN 9684 are marketed by Massey Ferguson (FIELDSTAR™) and Claas (AgroCom Terminal), although Muller Elektronik (Germany) has a unit, which can be coupled to a number of different types of application implements, mainly sprayers.

2.2.1 Job Computer (Implement)

The job computer for the implement differs from implement to implement. It is interesting to note that DIN 9684 allows up to 32 functions to be addressed via a single job computer on the implement. For a fertiliser spreader the job computer would typically receive the following information:

- Travelling Speed
- Amount of fertiliser to be spread
- Side control commands for field edges

For this, the job computer needs to be calibrated, store its calibration figures in a similar way to a data collection job computer.

2.2.2 Implement Requirements for Variable Application

Implements used for the implementation of variable application of inputs also need to meet certain requirements. These are:

- The implements need to be stepless, i.e. the adjusting mechanism may not have any discrete steps such as gears or ratios. Most 3-point mounted fertiliser spreaders, where the amount is adjusted by a slide, are examples. Most precision planters are not compatible, as they have discrete ratios. Most large companies (John Deere, AGCO, Kinze) have developed a hydraulic drive to overcome this problem. These hydraulic drives are expensive, as they need a feedback type control system, to maintain the correct speeds. Amazone (Marquering, 1997) has overcome this problem by using a stepless gearbox, where the ratio is adjustable by a simple lever. This makes implementation less costly, when compared to hydraulically driven systems;
- Very often precision planters (John Deere, AGCO, Kinze) are driven centrally from the main drive shaft, if both the seeding rate and fertiliser rate is to be varied, both systems need to be driven independently by hydraulic drives. The metering rate must follow the same curve on the upward and downward routes. It must also be possible to fit a mathematical curve to this metering curve. It is obvious that this curve must be repeatable;
- A job computer must exist for the particular implement;
- Software for the main unit must be written to control the unit.

It is important to realise that although an implement may meet all of the above requirements, it may still not be possible to adapt the unit (Marquering, Bellstedt 1999) to variable application.

3. POSITIONING SYSTEMS

Positioning Systems form a cornerstone of a precision farming system, as without precise positioning no geo-referenced work in real time is possible. The Global Positioning System (GPS) concept of operation is based upon satellite ranging. Users figure their position on the earth by measuring their distance from the group of satellites in space. The satellites act as precise reference points.

Each GPS satellite transmits an accurate position and time signal. The user's receiver measures the time delay for the signal to reach the receiver, which is the direct measure of the apparent range to the satellite. Measurements collected simultaneously from four satellites are processed to solve for the three dimensions of position, velocity and time.

GPS reached full operational capability on 17 July 1995, providing up to 1 May 2000 two distinct services, Standard Positioning Service (SPS) (access to the L1 band) and Precise Positioning Service (PPS) (access to both L1 & L2 bands). The SPS was intentionally degraded with Selective Availability (SA) to protect the interest of the US Department of Defence (DoD). SA was set to zero on 1 May 2000.

Although data collection can be done without real time correction, if the system collects sufficient information to allow post processing, it is far easier to use a real time correction system based on a Differential GPS (DGPS). The CLAAS systems used for the trials are not suitable to post-process data, as some information required for this step is not collected (mostly relating to time and satellite information).

3.1 Background on the GPS

The GPS consists of three segments:

- The space segment;
- The control segment;
- The user segment.

The space segment consists of 24 operational satellites in six circular orbits 20 200 km above the earth, at an inclination of 55° to each other. The satellites have a 12h period, and are spaced in orbit that at any time a minimum of 6 satellites are in view (i.e. signals can be received) of a user positioned anywhere in the world. The satellites continuously broadcast their position and time data to users throughout the world.

The control segment consists of a master control station in Colorado Springs, and five monitor stations and three ground antennas located throughout the world. The monitor stations track all GPS satellites in view and collect ranging information from the satellite broadcasts. The monitor stations send the information they collect from each of the satellites back to the master control station, which computes extremely precise satellite orbits. The information is then formatted into updated navigation messages for each satellite. The updated information is transmitted to each satellite via the ground antennas, which also transmit and receive satellite control and monitoring signals.

The User Segment consists of the receivers, processors, and antennas that allow land, sea, or airborne operators to receive the GPS satellite broadcasts and compute their precise position, velocity and time.

3.2 Factors affecting accuracy of the GPS

When the GPS signals were deliberately degraded using Selective Availability, the positional fix was accurate to within ± 100m. Although SA was set to zero with effect of 1 May 2000, the accuracy produced by a GPS is still only within 10-20m. These errors is position are due to the following:

- Satellite clock errors;
- Ephemeris errors;
- Ionospheric errors;
- Multipath transmission errors;
- Receiver clock errors.

Since the positional error caused by the above errors is typically larger than the required accuracy for precision farming, some form of GPS correction still has to be taken.

3.3 Principles of GPS Correction

All of the above errors affect the signal for each satellite in view of the user differently, as the distances, and elevation of each of the satellites varies. The simplest form (and most accurate form for short distances) correcting the GPS errors, is the method utilised by precision survey GPS, where a precision receiver is positioned at a known position, and the apparent range error (i.e. the difference in the distance measured and the real distance) is measured for each visible satellite. These apparent range errors, even with Selective Availability effects, appeared relatively stable over short time periods up to 30s as revealed by an analysis of some 29 000 positional fixes logged during NAMPO 1998 by the author.

These apparent range errors can then be transmitted via the appropriate format (RTCM SC-104) to roving GPS receivers, where the apparent range error for a particular satellite is added to the range received, and a more accurate positional fix is achieved. As a differential is added to each range, this technique is known Differential GPS or DGPS. This principle is depicted in figure 7.

However, as the apparent range errors vary from position to position and for each satellite in view of the user, new errors are created with this correction method, although infinitely smaller than the original errors. This, and as different satellites are in view of the user at different positions, limit the range of this technique to a range of some 750 to 1 000km from the nearest base station (NAMPO test, 1998; Hopetown tests, 1998 & Price, 1997), although the Chief Directorate: Survey and Mapping (CDSM) puts a (probably conservative) limit of some 400km to DGPS (CDSM, 2000).

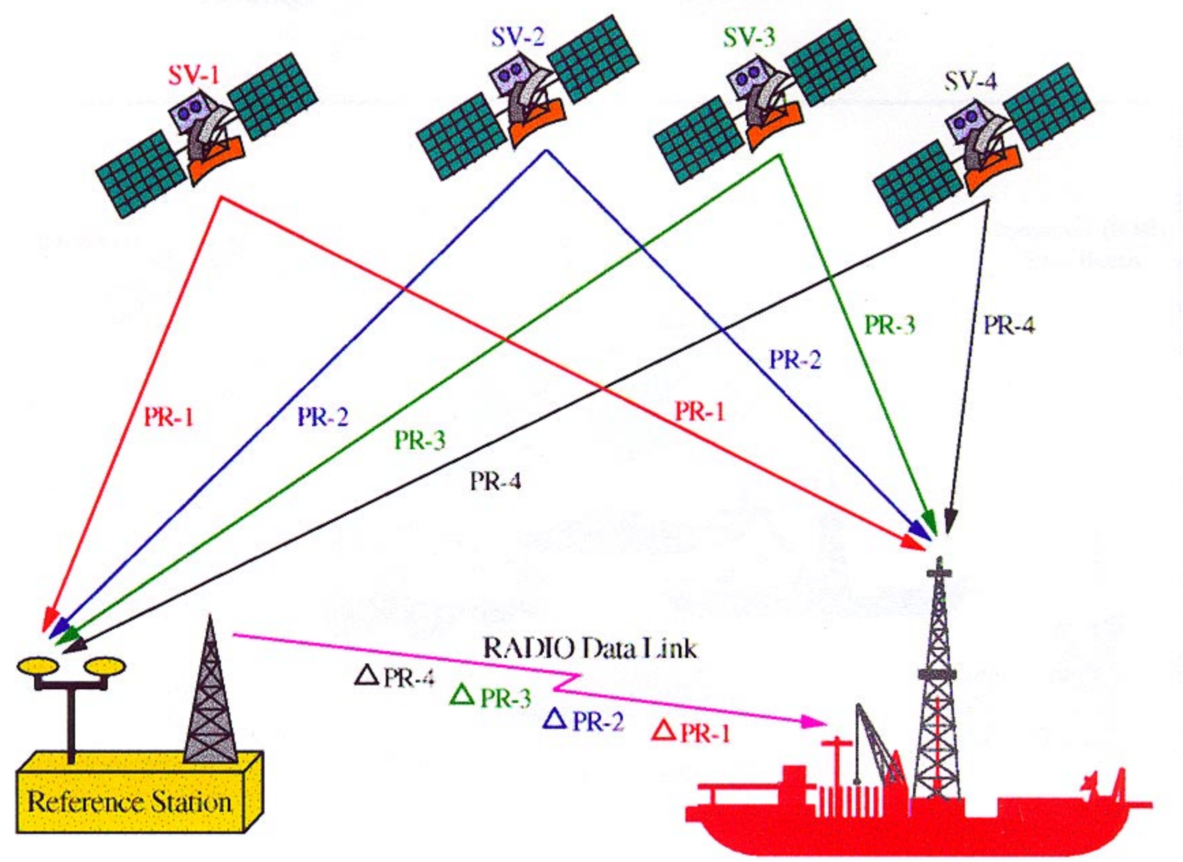

Fig. 7: Schematic layout of DGPS

This limitation, and the high cost of operating a reference station has led to the development of software solutions by (at least) two of the larger DGPS providers, RACAL (WADGPS) and OmniSTAR (VBS). It is beyond the scope of this report to provide detail on how these systems work.

3.4 Real-time DGPS

As DGPS, as described in its simplest form, has limited use, mainly because of transmission problems, alternative DGPS solutions have been developed worldwide. These are:

- Satellite based systems;
- Radio Data Service (RDS) or Data Radio Channel (DARC) based systems;
- GSM (Cellular telephone networks) based systems.

At present, only satellite based systems are available in South Africa, and the author has had experience with two of these systems, RACAL & OmniSTAR. In Germany a RDS correction system is in place, and open for use to the general public (Claas, 1997)

3.4.1 Satellite based DGPS

The radio data link shown in figure 7 is the weak link in commercial correction systems, mainly due to the following:

- Low transmission signal strength;
- Interference from other users / other radio signals (two-way radios etc.);
- Interference / obstruction from buildings, topography etc;
- Frequency allocation not tightly controlled, as anybody can operate radios in a given frequency range.

The combination of the above factors leads to a relatively low reliability of the radio links, and with the short range (<250km) of radios (Eskom surveyor, 1997), this is not a viable option to commercial DGPS suppliers.

For these reasons, satellite based systems were developed by a number of large operators, and as reliability of the GPS correction (with Selective Availability at the time of the tests) was considered important for the testing of the yield-mapping systems in South Africa, all testing was done with either RACAL or OmniSTAR satellite based integrated (combined) GPS/DGPS receivers.

Although both suppliers claim to have an advantage over the other (Smith, 1997; Price, 1997), and both boast similar capability, different systems with different setups were used for the tests. These were:

- RACAL MKIII combined GPS/DGPS receiver, with a Trimble DSM 12 Channel GPS card. This unit was used for the first tests in Swellendam (Lexion 460, First Yieldmap) and for tests in Hopetown. The unit was set to provide the proprietary TSIP output, as Claas required this at that stage. This unit was set to auto-select the closest base station;
- RACAL MKIII combined GPS/DGPS receiver, with a Trimble DSM 12 Channel GPS card. This unit was used initially for parallel test in large parts of the Free State in one of two Claas Mega 208 combines from a contactor. This unit was set to NMEA output, providing a GGA string, to match the requirements of the Claas ACT Terminal. This unit was set to auto-select the closest base station;
- RACAL MKIV combined GPS/DGPS receiver, with an Ashtech G12L 12 Channel GPS card. This unit was used to replace the MKIII receiver for parallel test in large parts of the Free State in one of two Claas Mega 208 combines from a contactor. This unit was set to NMEA output, providing a GGA string, to match the requirements of the Claas ACT Terminal. This unit was set to auto-select the closest base station;
- OmniSTAR combined GPS/DGPS receiver, with a Trimble DSM 12 Channel GPS card. This unit was used for parallel test in large parts of the Free State in one of two Claas Mega 208 combines from a contactor. This unit was set to NMEA output, providing a GGA string, to match the requirements of the Claas ACT Terminal. This unit was set to use the Virtual Base Station (VBS) solution as implemented by OmniSTAR;

- RACAL MKIV combined GPS/DGPS receiver, with a Trimble SK8 8 Channel GPS card. This unit was used for the Lexion 460 in Hopetown. The unit was set to provide the proprietary Trimble TSIP output, as Claas required this at that stage. This unit was set to auto-select the closest base station. Because of problems with TSIP both the Lexion 460 and this receiver were later changed to NMEA GGA output, similar to all other test units;
- RACAL MKIV combined GPS/DGPS receiver, with a Trimble SK8 8 Channel GPS card. This unit was used for the Lexion 480 of Paul van der Merwe. This unit was set to auto-select the closest base station and NMEA GGA output.

3.4.2 Problems Experienced with Satellite based DGPS

A number of problems were experienced during the tests. Some of these were related to installation, whilst a number were equipment related. The following errors occurred:

- The RACAL MKIII receiver was sensitive to the power supply, and lost most of its setup, if the power supply was cut or dipped below a certain voltage if the unit was powered. This caused a number of problems, as the setup was quite difficult, and a number of steps had to be followed in a specific sequence. A further problem was that RACAL utilised authorisation codes embedded into the correction signal, and these were transmitted only once every 20 minutes, but were required by the receiver at least once. This receiver was also sensitive to the antenna position, and the RACAL antenna needed to be at least 500-750mm clear above the combine. It seemed that the problem was low signal strength, which was easily cancelled by signal reflection off the smooth, flat combine surfaces. This caused problems with travelling on public roads, as well as telephone lines in fields. Since these receivers used a dual antenna system comprising a RACAL antenna, and a normal GPS antenna, two antennas had to be mounted. The RACAL antenna further needed a down-converter and one of these was lost to water ingress;
- The OmniSTAR receiver appeared to be sensitive to power spikes (caused by large consumers switched on or off) as one unit burnt out. OmniSTAR does not publish the exact elevation of the geo-stationary satellite transmitting the correction information, and at one stage a reception problem of this signal seemed to be caused by reflection of the signal off the smooth, flat surfaces. This was not as pronounced as with the RACAL MKIII receiver, but the antenna still needed to be some 250mm clear of the combine. The OmniSTAR receiver setup could also be changed by the user, and this happened once accidentally;
- The RACAL MKIV receiver was by far the sturdiest of the group, and the most practical to use. This unit used a single combined antenna, with a largely improved reception and the antenna could be mounted almost flush with the top of the combine. The unit has no power switches, and setup was done via a PC with special control cables. One failure happened, but it seemed a lightning strike as part of the antenna and unit were burnt.

3.4.3 Suggested DGPS System Configuration

Because combined units were used for all the tests, and at later stages NMEA was the standard protocol, troubleshooting was easy. Based on these tests, the following satellite based DGPS system is currently the system of choice:

- The system should either use an algorithm to determine and select the nearest Base Station, or still better use either a Virtual Base Station (VBS) solution, or a Wide Area DGPS (WADGPS) solution. These systems require access to the raw GPS position, to either select the Base Station (and also the correct satellite frequency from a table) or to calculate the correction for the raw position;
- To minimise interfacing hassles, and ease troubleshooting, a combined GPS/DGPS unit, based in a single housing should be selected, even if it means disabling an existing GPS unit in the combine (or as experienced in a Claas ACT). A high performance 12-channel receiver (Trimble DSM or Ashtech G12) is not a requirement, but at least a good 8-channel receiver (Trimble SK8) or a low cost 12-channel receiver (Ashtech G12L) should be used. The system should be GPS (US DoD system) based and GLONASS should at best be used as an enhancement (Position, 11/1998);
- The protocol is set as required by the supplier of the equipment to which the DGPS is connected. Claas originally used Trimble Standard Interface Protocol (TSIP), a proprietary protocol from Trimble. Although Trimble claims that this protocol, which some 40 command-and-response-packages allows the best control over their receivers, it is not supported by other GPS card manufacturers (Price, 1997). NMEA is used by most as a standard protocol, and different outputs can be set (GGA, VTG etc.) With NMEA checking the unit is fairly easy, as a PC loaded with HyperTerminal can be used to check the integrity of the output string. Whatever the requirements in terms of protocol, it is important to configure the protocol correctly;
- Optimally the system would require a single antenna, to ease installation. If a dual antenna system is used, the GPS antenna should be installed in the position provided by the manufacturer of the combine. This is usually in front of the cab roof, and lag time for the yield-meter may have been set for that position. The correction signal antenna need to be mounted high enough to get a clear view of the geo-stationary satellite for the position were combine operates, taking field slopes, grain tank extensions and elevation of the satellite into account. Refer to Appendix J for typical elevation and coverage maps;
- The system should have little user set-up possibilities, or these should be lockable to prevent accidental changes to the configuration;
- It may be of advantage to negotiate a geo-gated signal contract, where any number of receivers may be operated under one signal contract within a certain, defined area;
- Similar to the cellular phone industry, at least one signal provided has offered the receivers at a discounted cost, subject to a long-term signal contract.

3.5 Alternative DGPS Options

As the signal costs of satellite based systems are fairly high in South Africa (R12 000 to R15 000 pa per unit), a farmer interested in Precision Farming may want to find alternative way to provide an accurate DGPS service. As farmers typically will require a large number of DGPS systems for short periods of time, it is often not viable to buy commercial signals, even with geo-gating, as receiver cost are high. This line of though is confirmed by the resistance of farmers to pay large amounts for signal they use only for short times (van der Merwe, 1999; Osborne, 1999).

Although all tests done for this report utilised satellite based DGPS systems, a number of other options also exist, and these will be briefly discussed. These options are:

- Own base station with radio-based RTCM correction;
- Public Domain correction systems, as in use in Germany.

3.5.1 Own base Station

As radio links are fairly reliable for distances up to 100km, a group of farmers can build up a base station for use amongst themselves. Typical components would be:

- A PC with a specialised GPS card to calculate the apparent range errors for all visible satellites;
- A serial (RS 232) radio link transmission unit (20W) to transmit the RTCM messages;
- A GPS card and serial (RS 232) radio receiver unit per roving unit.

Although base stations may be fairly expensive to set up, and will require some standby equipment, the cost to operate the system should allow for considerable savings compared to commercial signals. Serial radio receivers are also less expensive that specialised satellite signal receivers, lowering the unit cost per rover.

3.5.2 Public Domain Correction Systems

In Germany, a Radio Data Signal (RDS) based correction system has been implemented for use by the public. This system uses existing radio station transmitters, and utilises the data signal capabilities of these to transmit RTCM messages. These can then be received via a simple (and cheap) FM receiver. Claas uses this system in its AgroCom terminal range, in combination with a combined antenna.

The CDSM, Mowbray is at present busy implementing a test stage of a public domain system, and it may be worth visiting their website at http://w3sli.wcape.gov.za to stay updated on the issue.

4. RESULTS OF SOUTH AFRICAN TRIALS

The first yield map was done in the Western Cape in the Swellendam area. This field, Canola, was cut into windrows to prevent wind losses. This yield map, attached in Appendix K (First Yield Map), was compiled on the 31st of October 1997. The yield map shows the inner part, 19.54ha of a field of some 35ha. By and large this map was, for the author, the acid test, as from the combine little or no differences in yield could be observed. When asking the farmer (Du Toit, 1997) on where he thought higher yielding areas where, he correctly pointed them out. He was, however, surprised by the differences in yield found in this field, but went on to explain that these were probably due to two fields being combined. The bar chart (on the map) gives the percentages of the field for specific yields. Broadly, it can be said that the variations in yields are larger than those reported from Europe (Moore, 1998) and that in some cases large parts of fields do not contribute to the profitability of the farm, but rather erode income. A variety of yield map were compiled under a variety of conditions, over large areas in South Africa, and the results are discussed under appropriate headings.

4.1 Dry Land Conditions

In this section a detailed analysis of the various yield maps gathered under dry land conditions throughout South Africa will be made.

4.1.1 Canola in Swellendam in 1997

This yield map, attached in Appendix K was the first yield map made with Claas equipment in South Africa. The following technical equipment was used for this map:

- Claas Lexion 460, equipped with a pick-up for swath use, to take up the 15m swaths made by the farmer;
- Integral quantimeter as installed by Claas in the combine;
- Racal MK III DGPS receiver with integrated DSM GPS card set to TSIP protocol for use with the Lexion. As this trial was done on a hilly field in the Southern Cape, care was taken to ensure a 'Clear Sky' view by the GPS/DGPS antennas of this receiver as the spot beam elevation was fairly low.

The raw data map is attached to the yield map, as is a map showing a combination of the yield map and raw data maps, and on this map it is evident that there are two data points out of position. As this was only detected after a detailed analysis, the reason (either left the track, or DGPS age / lost signal) is not clear. There are also various points were the effect of blockages caused by humps in the swath can be seen. These points do not need to affect the yield map, as the Kriging algorithm used in the calculation of the yield map can be adapted to correct the effects of such errors (Claas AgroMap User Manual, 1998).

4.1.2 Sunflowers in Wesselsbron in 1998

This yield map was made using the following technical equipment:

- Claas Mega 208, equipped with a row independent screw header (Plukker Van Die Mielie header, Paul van der Merwe)
- A Claas AgroCom Terminal with retrofitted quantimeter
- A DGPS receiver (either RACAL or OmniSTAR)

The maps are attached in Appendix L and show large areas with yields significantly below the average, and accordingly significant areas with yield higher than the average. There are also areas with a low number of points, as there were wet spots in the field. It is possible, with a different setting of the borderline calculation of the field, to have a different set of maps showing some islands. As a field should have only one borderline, this practise is not encouraged, and care should be taken with the interpretation of maps with data gaps.

4.1.3 Wheat in Reitz in 1997/8

These maps were made using the following technical equipment:

- Two Claas Mega 208, both with 7.5m headers, both retrofitted with Claas ACTs as under 4.1.2
- One Mega was equipped with a RACAL MKIII receiver, the other with an OmniSTAR receiver.

All 8 fields were mapped by the two combines together, with the raw data of the one combine and the other shown separately in Appendix M. These raw data files were then combined, and the separated into the 8 different fields. In this regard it was, as the Claas quantimeter is a volumetric system, important to set both machines using the same parameters. The yield differences are quite large, but there are also encouraging signs in these maps. These are:

- The yield differences show some consistencies, regardless of the combine used;
- The raw data sets match nicely, even with the two different DGPS providers used;
- The yield differences show certain patterns across field boundaries;
- Most yield differences were reasonably well explained by the farmer, showing the importance of local knowledge.

4.1.4 Maize in Reitz in 1999 and in Viljoenskroon in 1998

These maps were made as follows:

- The Viljoenskroon field was harvested with a Claas Mega 208 with a row independent screw header (Plukker Van Die Mielie header, Paul van der Merwe), equipped with a Claas ACT quantimeter and DGPS system;
- The Reitz field was harvested with a row independent screw header (Plukker Van Die Mielie header, Paul van der Merwe) fitted to a Lexion 480, equipped with a Cebis based quantimeter and a RACAL MKIV DGPS.

Two yield maps of the Viljoenskroon fields are attached in Appendix N, these are largest fields tested (both at over 100ha each). As in the Wheat in Reitz maps, there are also some patterns across field boundaries. There are also strong patterns within the fields, showing large

differences in yields. The field Stev1 should, under normal agricultural conditions, be treated as at least 3 separate fields, and the field Stev3 could also be divided into at least 2 fields.
Three of the four fields mapped with maize in 1999 are under the eight fields previously mapped for wheat in 1997/8. In these fields also large differences in yield can be found, as are certain patterns crossing the field boundaries.

Generally the yield differences under dry land conditions are very large. If input costs amount to say 80% of average yield, then it can be deducted that large parts of the dry land fields investigated here do not contribute, or even erode farm income. In some instances it could be practical to divide larger fields into parts, such as Stev1 and Stev3, but in other cases where the low and high yielding areas are intertwined within the field, this approach is not practical. The fields in Reitz all fall into this category.

4.2 Irrigated Conditions

Although quite a number of trials were done under irrigated conditions, these were in principle all on one farm in the Hopetown area. The data of two pivots in the Free State area is also shown, but for reasons discussed, these trials are of little value. Both wheat and maize were mapped, and the results by and large show variations, but to a lesser extent than under dry land conditions.

4.2.1 Wheat in Hopetown

A number of small trails in wheat were done in the Hopetown area, partly during demonstrations with the Lexion 460, and partly with the farmer who bought the combine. Some of the smaller fields are attached in Appendix O, and although small by South African standards, these fields would be normal sized fields in many parts of Europe, especially Southern Germany. A number of larger fields were also harvested, and some complete 60ha pivots are also attached in Appendix O.

4.2.2 Maize in Hopetown

Maize in Hopetown was harvested on a number of pivots, mostly 60ha in size. These maps are all attached in Appendix P. Some of these fields are identical to the ones in Appendix O, but this will be discussed separately. These maps were also made with the Lexion 460. Some Popcorn trials were also harvested, and apart from the generally lower yield with popcorn, the variations are in the same order.

4.2.3 Maize in Bultfontein

Maize in Bultfontein was harvested on two pivots. These maps are attached in Appendix Q. The trials were marred by the extremely wet conditions experienced late that summer, were some parts of the fields suffered from waterlogged conditions for extended periods. It was also difficult to harvest, as the MEGA 208 got stuck on a number of occasions. The maps are probably for interest only and have little value.

4.3 Repeat Trials

Although most trials were a once-off exercise, some fields were harvested twice, or even 3 times during a 2-year period. As precision farming is about long-term trends for the particular sub-fields, these were the most interesting, and also most important trials. These trials were to confirm the theory, and also confirm the repeatability of tests.

4.3.1 Dry Land Conditions in Reitz

The trials described under 'Wheat in Reitz' and 'Maize in Reitz' were done on the same farm, at an interval of some 18 months. The farmer plants alternatively maize and wheat on his total farm, and with this method keeps the soil profile relatively full (i.e. the available water). During the rest period, the fields are worked only if weeds become a problem. These trials are especially interesting, as they were with a combination of virtually all equipment on test at that stage in South Africa.

It is very interesting to note that generally the same patterns occur in these fields, and more importantly across field boundaries. These trials confirm that yield mapping, and as such precision farming, is no gimmick. It may be concluded that the variations observed are large and repeatable.

It is unfortunate that any further trials on this farm have been suspended, as extensive soil sampling was done on the two largest southern fields. A sampling plan of field 7 (Omnia field 14) is attached in Appendix R.

A series of soil maps by Omnia are attached in Appendix R. These were calculated using an average value algorithm (Lourens U, 1999). The same data was transformed into AgroMap Basic, and the Kriging algorithm was used to calculate soil data maps. As the Kriging algorithm was specially designed for yield-mapping purposes, were some data points have to be disregarded, this approach yields some areas on the soil value maps, which show incorrect values. These maps are also attached in Appendix R.

4.3.2 Irrigated Conditions in Hopetown

The irrigated fields in Hopetown, as described under 4.2.1 and 4.2.2, do not show the same repeatability as the dry-land trials in Reitz. This may be due to a number of reasons:

- The fields are irrigated, and therefore will show different limitations (yield seems not limited by water);
- As these fields are double cropped, with some 6 month per crop (Wheat from June to late November / early December, Maize from December till May), it seems that there may be influences other than nutrients and/or water limiting yield of these particular fields. Le Roux and the author (1998) discussed this during the trials done on his farm (see Appendix C for Map). On this particular field, low lying sections had suffered from frost damage because of relative late planting;

- The soils of the pivots (as per the authors visual observation) were of a much more uniform nature. Due to some (GPS) problems with this particular combine, information on the one or two pivots with substantially less uniform soils was never collected;

These results show that in under these intensive irrigated conditions one may need more yield maps to be able to deduct the truly limiting factors, and how to address these. Different results can also be expected if the fields are not double cropped, and planting times can be closer to the optimum time (for maize this difference may be up to 2 months in Hopetown).

4.4 Summary of Results

A farmer can only continue farming if he has a positive return on investment, at his chosen interest rates. Precision farming, to some extent, is about raising this profitability, while having other positive spin-offs. Traditionally, a farmer has looked at the yield of a field, and compared this to his input cost (inclusive overheads) to decide if it is viable to continue farming that particular field.

Although many farmers knew that some parts of their fields were contributing less to the farm income than other part, they were unable to quantify this. Precision farming for the first time allows one to quantify how much each part of the particular field contributes. From this, one can establish gross margin maps (Moore, 1998). This is in the context of this report an academic exercise, as this would require precise input costs.

As result the assumption has been made that for any field described above, the input cost represent 70, 80 or 90% (Cost to Income Ratio, C/I) of the gross revenue for a field. The author is aware that this is a simplification, but using this method shows what percentage of the fields contributes to farm income, and which parts erode farm income. For comparative purposes, these results are tabled below.

Field (Appendix)	**Crop** (Year)	**Average Yield** (t/ha)	**Percentage of field area not contributing to farm income**		
			C/I: 70%	C/I: 80%	C/I: 90%
First YieldMap (K)	Canola 1997	1.59	6.36	11.94	27.5
Landskroon 3 (L)	S/flower 1998	2.25	17.3	26.10	35.71
Land 1 (M)	Wheat 1997/8	3.00	35.98	43.42	50.66
Land 2 (M)	Wheat 1997/8	2.35	28.72	37.64	46.96
Land 3 (M)	Wheat 1997/8	2.98	30.32	38.11	45.75

Field (Appendix)	**Crop** (Year)	**Average Yield** (t/ha)	**Percentage of field area not contributing to farm income**		
			C/I: 70%	C/I: 80%	C/I: 90%
Land 4 (M)	Wheat 1997/8	2.79	34.38	43.45	52.25
Land 5 (M)	Wheat 1997/8	2.72	27.03	36.85	46.79
Land 6 (M)	Wheat 1997/8	3.05	34.20	42.52	50.87
Land 7 (M)	Wheat 1997/8	3.20	41.01	47.95	54.82
Land 8 (M)	Wheat 1997/8	2.33	35.61	43.06	50.19
Land 5 (N)	Maize 1999	2.60	33.33	38.94	45.23
Land 6 (N)	Maize 1999	2.94	30.81	37.30	44.48
Land 7 (N)	Maize 1999	2.41	33.61	39.18	45.05
Stev 1 (N)	Maize 1998	4.75	31.34	38.63	46.58
Stev 3 (N)	Maize 1998	3.82	23.97	32.68	41.17
Joubert & Verst. (O)	Wheat 1997	7.85	10.77	15.01	30.76
Le Roux (O)	Wheat 1998	6.53	8.97	19.99	34.02
Reid (O)	Wheat 1997	10.17	11.47	13.12	24.55
Pivot 1 (O)	Wheat 1997	7.44	9.02	13.08	23.38
Pivot 2 (O)	Wheat 1997	7.99	5.14	10.03	28.96
Pivot 3 (O)	Wheat 1997	7.24	3.31	10.76	18.94
Pivot 11 (O)	Wheat 1997	6.48	8.98	17.99	29.76
Pivot 13 (O)	Wheat 1997	7.70	5.89	12.97	28.85
Pivot 1 (P)	Maize 1998	9.90	2.79	5.76	26.98
Pivot 1 (P)	Maize 1999	9.08	20.74	24.33	38.86

Field (Appendix)	**Crop** (Year)	**Average Yield** (t/ha)	**Percentage of field area not contributing to farm income**		
			C/I: 70%	C/I: 80%	C/I: 90%
Pivot 2 (P)	Maize 1998	8.69	11.77	20.17	28.56
Pivot 3 (P)	Maize 1999	8.23	16.54	24.92	33.68
Pivot 12 (P)	Popcorn 1999	4.44	27.53	31.87	36.30
Pivot 13 (P)	Maize 1999	8.42	19.27	27.95	37.32
Spilpunt 1 (Q)	Maize 1998	6.22	21.09	27.74	34.28
Spilpunt 2 (Q)	Maize 1999	9.08	20.74	29.33	38.86

Table 1: Percentages of field areas not contributing to farm income

4.5 Technical Observations

Some technical problems have been found, mainly due to the way certain crops were harvested, and also due to the way the yield monitor works. The following is noted in this regard:

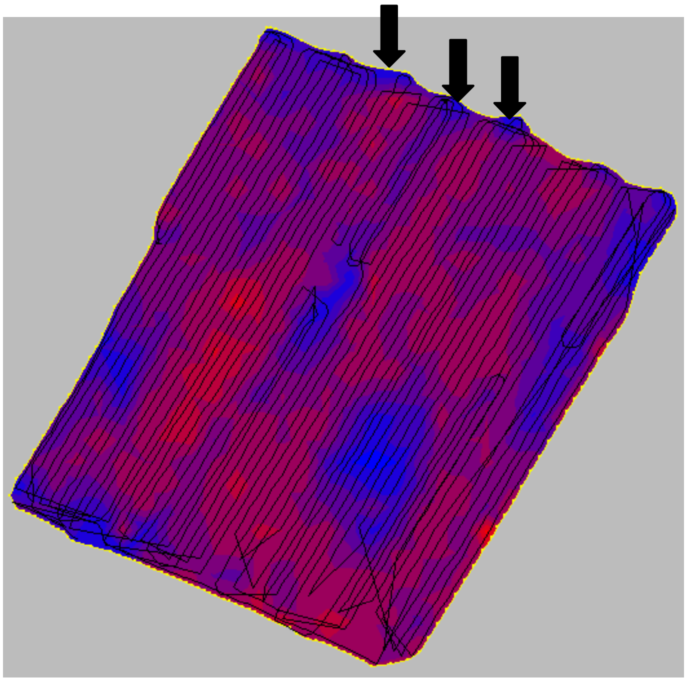

Fig. 8: Yield map showing erroneous field edges

- If a combine operator follows certain driving patterns, some of the results at the edges of the field are not correct. This is illustrated in the figure 8. This is as a result of the combine stating empty at the beginning of the track, and taking some time (more than the lag time in semi-steady-state) to register quantities. A similar problem has been encountered in the Canola field in the Southern Cape, see Appendix K;
- When harvesting wheat on pivots, a semi-elliptical pattern is often followed. This creates arcs showing low yielding areas, as shown in figure 9. These arcs are not truly low yielding and care has to be taken in evaluating the results.

4.6 Conclusion (of Results)

It may be concluded that all results gathered during the nearly 2-year period show large differences in yield. The possible exception to this seem to be the double cropped fields in Hopetown, where differences in yield are markedly lower. There are, however, some very encouraging results, showing the following:

- Yield difference patterns are not limited by field boundaries;
- Yield difference patterns are largely repeatable, and show that limiting factors occur, and influence results;
- Yield difference occurs across different crops, and in some cases this difference followed largely identical patterns for different crops;
- Yield difference patterns are not influenced by a particular combine, or combinations of combines;
- Yield difference patterns are influenced by certain driving patterns, and may lead to misrepresentation of yield;
- The different DGPS systems all worked seamlessly, and data could be integrated without problems.

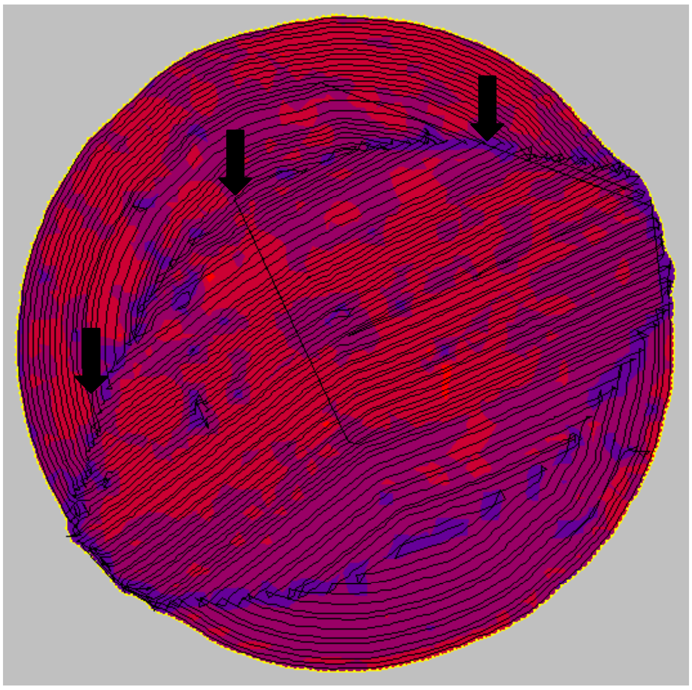

Fig. 9: Yield map showing erroneous low-yielding arcs

Although a number of problems were encountered when introducing the yield-mapping technology in South Africa, this technology is exciting as, for the first time gives farmers the opportunity to farm on a large scale yet pay attention to small differences with regard to crop limiting factors.

5. PRECISION FARMING AND COMPUTER AIDED FARMING SYSTEMS

Precision farming has been described in some detail in section 1 of this document. It follows that the amount of data involved and its processing can only be done with the aid of a computer system, normally a PC. As precision farming centres very strongly around the profitability of a farming operation, and since the majority of decisions are at least in part based on economics, Computer Aided Farming Systems (CAFS) need to be introduced here.

Although Fenton (MFUK, 1995) argues that precision farming and CAFS are very much synonymous, the author disagrees. With no other references found to the term, CAFS is very much a tool for the farmer, whereby the decision-making processes on the farm are assisted. This assistance is more in the form of readily available data and speedy processing enabling the farmer to do various ‘what-if’ scenarios before committing a specific amount of resources to a particular field.

Precision farming (in its final form) is not possible without CAFS, but precision farming is no prerequisite to CAFS. In implementing precision farming, an existing CAFS will help to get the farmer going, as precision farming will only be an extension of CAFS (adding more, but smaller fields).

5.1 Computer Aided Farming System (CAFS)

In precision farming, fields are usually subdivided into individual sub-fields of some 20 x 20 m, this ‘creates’ 20 to 30 sub-fields per hectare. Ideally the farmer can now, for each sub-field, follow the same decision making process he usually does for larger, individual fields, or in some cases even complete farms. Figure 4: Flow diagram for decision support depicts the typical decision making process of a farmer – be it on a sub-field, field or farm(s) basis. The factors influencing decisions can largely be grouped in two categories:

- Factors influencing all sub-fields;
- Factors influencing only individual sub-fields;

Given the large amount of combinations of possible crops, and all factors influencing, a farmer can, with traditional methods, only investigate a limited number of options for his farm, or at best on a field basis.

A Computer Aided Farming System (CAFS) is no more than a computerised decision making system, which can take all factors into account, and doing the onerous, repetitive number crunching for the farmer. One has to be very clear about the processes: the decision-making process is not taken over by the computer, but aided by the computer. As in all systems, the output is directly dependant on the input, and one cannot expect good output on dodgy input data.

CAFS makes it possible for the farmer to investigate more options on more fields, thus allowing him to reduce the size of his fields (to sub-fields), and therefore optimise his operation in respect of his personal strategies, taking all other limiting factors into account.

5.2 Compiling Additional Information

The yield maps collected in the previous step only represent a part of the information that needs to be gathered for effective decision taking using CAFS. Additional information for effective decision taking needs to be gathered. The information required can be grouped into two categories.

5.2.1 Factors influencing all sub-fields

There are a number of factors that influence the whole farming operation. These factors can further be divided into those over which the farmer has no control, and those over which he has some control. The following factors are discussed:

(a) Interest Rates

The farmer has limited control over combined interest rates, as these are made up of the interest rate charged by banks on his debt (if any) and the return he would like to see on his personal investment. The return of his private investment may also vary as the enterprise develops. Initially, the farmer may be satisfied with a very low, or even no return, but as his operation matures, he may want to have higher returns.

(b) Weather and climate

The farmer has no control over the climate, or the weather for the particular season. He can, however gather information on the climate, analyse it statistically and create certain weather groupings for which analysis can then be done using the CAFS.

(c) Political

The farmer has no control over the wider political happenings around him. However, some of his decisions may be influenced by political pressures and happenings from around the world. Political factors (such as war in the Middle East – North Africa region) may not only influence produce cost, but also cost of inputs such as fuel and fertiliser.

(d) Distance to Markets

The distance the farm is located from the various markets (or transport nodes such as airports) will have an influence on the crop choices, and farming practise. As a rule a larger distance from markets will require production of products with a high value density (such as nuts), or be in a unique position to produce products to coincide with specific occasions. (The production of table grapes in the Blouputs – Onseepkans region of the lower Orange River to reach Europe in time for Christmas is an example)

(e) Estimated Crops Elsewhere

Crop estimates around the world have a bearing on world market prices for crops, and these will influence the outcome of decisions relating to the most economic production. If, for example the crop estimates for wheat show a surplus, then the marginal product for wheat production will be lower.

(f) Stocks

Carry-over stocks from previous seasons will also influence pricing of crops. Although the local crop estimate for a particular season may be lower than the requirement of the local market, there may be significant stocks remaining and in combination may be in excess of local requirements.

(g) Futures

Futures on the stock markets are a way for the farmer to hedge some of the risks associated with selling his produce. However, futures in itself can pose risks as they are offered on the perceived future market conditions. These may not realise. Compounding the problem seems to be the El Nino / La Nina phenomenon, where the start of the rainy season is a bad indicator for the expected season.

(h) Environmental Factors

Farmers have, in Europe, been under pressure as large polluters of the environment. As water resources get scarcer, and more closely monitored, together with a ‘polluter pays’ principle under the National Water Act, Act 36 of 1998, this pressure will increase. John Fenton argues (MFUK, 1995) that with CAFS / Precision Farming the total leaching of Nitrogen on his farm was reduced by some 60%.

(i) Personal Strategies

This factor is probably the only factor over which the farmer has full control. He can decide on where in the rational production zone he wants to produce.

5.2.2 Factors Influencing only Individual Sub-fields

Likewise, there are a number of factors that influence the decision-making process for a particular field, or in precision farming, sub-field only. Generally these factors will not directly influence other fields or sub-fields. However, there may be indirect influences, as a particular field may not be suitable to a certain crop, and thus influence the crop rotation of the whole farm.

(a) Soil (Physical and Chemical)

Full details of soil properties need to be recorded. Ideally this would be down to sub-field level, but given the size of these fields, cost will be a prohibitive factor. For the fields done at Reitz, one sample per 2 ha was taken.

(b) Suitability to Particular Crops

The suitability to particular crops needs to be assessed for the particular sub-field. In assessing the suitability a ranking is also needed (i.e. the field is suited to both crops A & B, but in the absence of any other factors, crop A is more suited).

(c) Yield Potential for each of those Crops

A detailed yield potential will have to be compiled. Ideally, this potential will be linked to a certain nutrient status, and for a normal rainy season. Allowance will have to be made for predecessor crops, which influence yields (e.g. wheat after beans will have a different potential to wheat after maize).

(d) Responsiveness to changes in Application of Inputs

For all inputs (macro, micro nutrients & weather) a responsiveness curve will have to be compiled. These need not necessarily be in fine detail initially, but need to give some indication what will happen. For some inhibitors (such as say aluminium) this may be toxicity, expressed as a negative responsiveness.

(e) Correlation to other Data in the same Sub-field (such as Interdependencies of say Mg and K)

If a correlation exists between certain inputs, these need to be recorded as well. These correlations will typically be in the form of nutrient A will only be efficient if at least a minimum (or not more than) of nutrient B is present.

5.3 Sources for Additional Information

The requirements for additional information is huge, but there are as many sources. One can divide these sources into passive and active sources, where passive sources would be literature available from many sources, and active sources would be participation in research programmes from various institutions.

5.3.1 Passive Sources

Information is available from a number of institutions, often free of charge. A few are listed below.

(a) Climatic Information

Climatic information is available from the Weather Bureau in Pretoria. Data can be provided for rainfall stations throughout the country for rainfall and temperature stations. This data can be analysed to suit the requirements of the CAFS. Climatic data has also been analysed by the Computing Centre for Water Research at the University of Natal. South Africa was divided into 709 homogeneous climatic zones, with specific data available for each.

(b) Irrigation Requirements

SAPWAT, from the Water Research Commission (WRC, 1996) can be used to calculate irrigation requirements for specific crops for the climatic zones as defined by the CCWR. CT Crosby developed this program. As all WRC publications, this is available free of charge.

(c) Information regarding Crop Growth / Nutrient Interaction

This information is generally the most difficult to find. However, very often, good indications are available from study groups, and also from fertiliser companies' local representatives. Results from research is also often available from the universities.

(d) Internet-based Information

The Internet has a host of available information on agriculture in the first place, and precision farming in the second place. Search engines, when used properly, can yield an enormous amount of links to research done worldwide. It is important to note that often research was done under different conditions. However, at the same time certain relationships (between nutrients) still remain valid.

It has to be noted, that whilst it would be ideal to have access to all the information listed above, this is usually not achievable and is also not required. The implementation of precision farming on a farm will lead to the discovery of more and more interdependencies of inputs. The farmer can then quantify these. It is the author's view that initially more questions will be raised than answers gained from the system, but that over time more and more answers will be researched.

5.3.2 Active Sources

Active data sources are the active participation in research programmes. If a farmer, or better study group, wants to get involved in graduate study programmes, he will have to contact universities in that regard. Very often research can then be tailored to a specific problem, or relationships in that area. The farmer will have to set aside time for the students, and also allow trials (on the test and control fields).

Active sources can also be yield trials done by the ARC, Seed companies as well as fertiliser companies. Although all of these active sources will have different aims with their research, the farmer can participate, and gain valuable information.

In the next section, access to active sources is described under ‘Strategic Alliances’.

6. A STRATEGY FOR PRECISION FARMING USERS IN SOUTH AFRICA

The implementation of a precision farming system on a particular farm can be a relatively daunting exercise. Yet at the same time one has to realise that this technology has made its mark in North America and in Europe. With the growing pressure from environmentalists and politicians on agriculture to reduce pollution, as well as growing economical pressure on the farmer, this technology has to be welcomed.

However, at the same time one has to realise that a farmer can only make an investment if he can achieve a positive return on it. In this section the author tries to give some guidance on how to implement a precision farming system, enabling the farmer to go through the learning phase associated with it, and at the same time minimise cost of the system.

6.1 Base Assumptions

For this strategy, the author will make a number of assumptions; these can also be the ‘Point of Departure’ for a farmer wishing to implement a precision farming system. These are:

- The farmer is financially stable, and has some financial reserves;
- The farmer is reasonably computer literate (for CAFS);
- The farmer has historical records of his inputs and outputs on a field basis;
- The farmers operation is in the ‘rational production area’ (Standard Bank, 1988)
- The farmer is reasonably willing and able to adopt new technologies (Rüsch, 1993)

A farmer contemplating to implement a precision farming system is not required to meet all of the above criteria (e.g. he can do without being computer literate). However, the above assumptions will make life easier.

6.2 Starting the Precision Farming Circle

Precision Farming is a long-term exercise, where gains on inputs are usually only made after a number of years. Yet examples from Europe (Massey Ferguson, UK, 1995) show that the rewards can likewise be extreme. For example, John Fenton has reduced his Nitrogen (as N) from 220kg/ha to 160kg/ha, albeit assisted by additional technologies such as nitrogen inhibitors.

6.2.1 Strategic Alliances

Starting a precision farming system involves a significant amount of skills, and, to some extent financial resources. It may be an option to strike strategic alliances, much the same as John Fenton and Massey Ferguson have done in the UK (Wright, 1999). The basis for these must be to create a win-win situation, where all parties feel that they gain during the alliance.

Typical alliance partners can be the farmer, his fertiliser supplier, his machinery supplier, a contractor, a DGPS signal provider (initially) and an agronomy department of a university close by. All of these partners bring different skills with them, and not all are necessarily required. It may also be an option for a typical study group to form the alliance, such as the Losdorings group (Muller 1998). The author, for the trials reported, set up an alliance with a large commercial farmer, a contractor, a fertiliser supplier and a DGPS signal provider.

Alliance partners need to chosen with some care, as one does not want to jeopardise crucial steps.

6.2.2 Setting aside the Test Fields

Setting aside the test field is the first crucial step in the precision farming circle. A test field must largely be representative of the farm, and for the partners, of the area. This should also be the point where the different interests of the various parties are discussed, as these will influence the operation of the alliance.

The test field must be large enough to warrant moving machinery (such as large combines or special applicators) to the farm, and make it economically viable to the parties. It may be an option to arrange additional work on the farm or within the study group area to make movements viable for the contractor. On the other hand the test field must be small enough that it does not influence the bottom line of the farm too much.

6.2.3 The first Yield (Value) Maps

The first yield (value) maps should be gathered at the first possible opportunity. This may take some preparation, especially if the yield monitor in the combine is a retrofit unit. The unit needs to be calibrated, and checked against real yields (on a field basis). All interactions between the various sub-systems (see also Technical Components and GPS Systems) need to be checked. The operator of the combine needs to be trained to use the system, and be confident to set the various parameters, as some of these need adjusting while harvesting.

After the first trial operations (not on the test fields), data needs to be transferred to a PC, and processed. This data should be processed immediately, to verify that everything is working as it should. Once this is completed, the test fields should be harvested.

6.3 Trials on the Test Fields

Precision farming lends itself to trials on a field basis. Moore (1998) & Fenton (MFUK, 1995) both suggest that variety of trials can be undertaken, and that, with yield maps from previous seasons as background, the possibility exists to extract the additional gain (or loss). The following trials can (and for learning purposes should) be undertaken.

6.3.1 Seeding Rate Trials

In Europe (Moore, 1998) a variety of seeding rates have been tested. Seeding rates were usually adapted where there are germination problems in fields. Already in 1985 Horsch in

Germany had adapted a seeder to the specific requirements of a farmer in central Germany. This machine could adapt seeding rates by approximately 20% when problem areas were entered (Rüsch A, 1985)

In South Africa all indications are that seeding rates are a function of available water (Lourens A, 1999; Botha, 1998). Therefore, seeding rates will not so much be adapted to establish a certain amount of plants per area, but to see what the optimum amount of plants per hectare is. Certainly the development of different cultivars with high yield potential will leave large room for seeding rate trials.

For seeding rates trials the farmer should not plant one half of the field at one rate, and the other at a different rate, but plant alternating strips of say 25 m wide using different rates.

6.3.2 Variety Trials

Different varieties will perform differently under different circumstances. Botha (1999) has for some time planted 3 different cultivars in the same field. His argument is that he lengthens the time available for pollination. Together with traditional cultivars (all with approximately the same growing period), seeded at very low rates (some 12 to 15 000 plants per ha) for the area, he achieves above average yields, with excellent drought resistance.

For variety trials, the farmer needs to plant a base cultivar for a field. In this field other cultivars are then also planted, with strips of the base cultivar of both sides of the test crop. Care has to be taken to ensure that the strips are a multiple of the header to be used for harvesting. In the fields in Reitz (as described in section 4), problems were encountered to harvest variety trials, as the strips were only some 4,5 m, but the header used was 12 m wide. As result the strips were harvested using a side only of the header, resulting in losses, and placing the strip in the wrong position on the yield map. This rendered the yield map useless.

6.3.3 Fertiliser Trials

Similar to seeding rate trials, fertiliser trials can be undertaken. Again, a base rate needs to be established, against which the trials are to be conducted. Likewise the strips should be wide enough to be harvested with a modern large combine.

The following are some examples of possible fertiliser trials:

- Variations as to the solubility of the fertiliser;
- Variations as to the split of the applications;
- Variations as to quantity;
- Variations as to (underfoot) placement;
- Variations as to liquid / dry / NH_3 gas;

A whole variety of possible combinations can be done on a field, once a basic yield trend has been established.

6.3.4 Seed Bed Preparation Trials

Possibly these trials should be called ‘tillage trials’. With precision farming, the farmer can do a whole host of different trials to establish for his circumstances the ‘best practise of tillage’. The author (Rüsch, 1999) prompted a set of trials in Hopetown, whilst evaluating some equipment for Massey Ferguson SA. These trials were done under centre pivot irrigation and included the following:

- Chiselplough in combination with a no-till planter;
- Tandem Disc, followed by a power harrow and conventional planter;
- Mouldboard plough followed by a conventional planter;
- No-till planter
- Power harrow followed by no-till planter

The standard practise on that farm was to burn, plough and plant (sow) after harvesting. Yield for the trials varied from 8.36 t/ha to 7.29 t/ha.

These trials were not ideal as the control / test / control / test… strip approach was not followed. Harvesting was done without yield meters, but the crop was weighed on the on-farm vehicle scale.

6.3.5 Conclusion (of Trials on Test Fields)

Trails on the test fields must be seen as a part of the key to understanding all those interdependent factors influencing crop production. As can be seen from the above-suggested trials, one could do trials forever without gaining definite answers to the problems. Compounding this if the rapid development of new technologies of production.

It would therefore seem prudent to find initial starting points for trials, and these should be based on desktop studies of relevant research. The aim here must be to weed out certain suggested techniques, based on previous trials and, most important local knowledge of both the farmer and his colleagues in study groups.

Likewise it seems equally important to be open to new ideas, and to take what seems good from a variety of techniques and combine it into a new method.

7. FUTURE DEVELOPMENTS IN PRECISION FARMING

Precision farming is an exciting tool, as can be seen from the previous sections. Information Technology (IT) is changing the working environment, as we know it today, faster and faster. On the other hand there is a significant amount to be learned for these systems to be really effective and efficient. A third tier of development will be in the data collection equipment, both farmer collected data and remote sensed data.

The future development can be divided into areas described below.

7.1 Development of the Technical Equipment

It seems that the technological development will focus on data collection, and ease of use of machinery. As described in the previous sections, data collection can be earthbound (data can be collected with each trip over the field) or spacebound (data is collected at specific time intervals via low-altitude satellites) In this section, an attempt will be made to look into possible developments in this field, following a description of current technology.

7.1.1 Earthbound Equipment

(a) Current Technology

Over the past few years, first generation tractor control equipment has been developed (Service Handbooks, various dates & manufacturers). Most of these control systems were designed to control functions (such as switching the PTO based on load, modulating differential locks, ELCs etc). However, Massey Ferguson and Fendt (Sales documentation, undated) have started to implement some second-generation control functions to their tractors. The Datatronic system from Massey Ferguson can limit wheel slip of the tractor, and regulate working depth to keep wheel slip within certain limits.

In combines, with the introduction of the Lexion range, Claas has gone the next step: A fully computerised combine where all settings can be done and verified from the cab. Included in this system is an information system based on ‘need to know’ policy that only show information when some decision needs to be taken (the system for example does not, during harvesting show any engine parameters, save when they exceed safe limits). Whilst a pleasure to work with (as one can adjust some settings just on entering different conditions), the system (in Germany) comes with a 3 day course before the handbook is handed over to the client. It is, at times, downright scary to fix the system (for example, upgrading the software of the CEBIS computer due to TSIP/NMEA changes, forced the author to change some electronic modules as these were no longer compatible – this was not documented. This rendered the combine unusable until the replacement part was installed). Also, in event of a computer failure, the combine’s motor protection unit will cut fuel supply, preventing any work from being done.

On the application side, Amazone must rate as one of the companies most advanced in variable technology, as it has a complete range of fertiliser spreaders, seeders, precision planters and crop protection sprayers adapted to variable technology. Amazone has also introduced a fertiliser spreader varying application rate in field based on real-time measurements of vigorousness of growth.

(b) Future Technology

Future development is this area will probably focus on providing much more functionality for the operator, to free him for other tasks. Some of the other tasks the operator can then handle are:

- Flagging of certain conditions in field, such as cut-worm damage when spraying;
- Fine-tuning of application, based on application maps and real-time observations.

Application technology will also be fine-tuned, but the author expects that various technologies become more and more integrated. At present, if an application map has been created on the PC, this can hardly be varied during application if the conditions are perceived to be different. However, it seems that fuzzy logic controllers may combine historical data (from the CAFS) and observations during application in real time. A typical example could be an area that historically has a low yield, but that vigorousness sensors detect untypical growth in that field section that requires more nutrients.

Further developments will certainly be in the data collection, where every trip over the field collects data. As there is a move towards complete electronic bus systems in machinery (Various manufacturers literature), useful data for collection will become readily available without additional sensors. A readily available (without charge) DGPS will certainly contribute to this.

On the sensor side, it seems in the pipeline that weed-pressure will be recognised from images taken while travelling, and that for example herbicide application is limited to areas where only threshold density of weeds exist. One could then also apply additional nutrients to areas where weeds have competed with crops.

7.1.2 Spacebound Equipment

(a) Current Technology

Currently remote sensed images (from Spot and other satellites) are commercially available through professional providers such as the CSIR. These images have typical resolutions of 10-20m (QOP 410 notes, 1992) i.e. the pixel size is some 100 to 400 m^2. As result it becomes fairly difficult to interpret these images, as each pixel represents the average of the conditions as seen from the camera.

There are a variety of different types of images available, such as true colour, false colour or infrared. Each of these, on its own can indicate a different set of conditions such as vigorousness of growth, certain disease conditions (such as blithe) or crop type (it is possible to distinguish between bluegum and pine plantations).

The present level of interpretation is probably only in the infancy stages, and much is still to be learned.

(b) Future Technology

If one considers how many times NASA has upgraded the Hubble (http://www.nasa.com) space telescope during the past few years, and what the corresponding performance increases of the telescope were, this gives some indication of what is to come in spacebound technology. It seems possible that in future grid sizes (for commercial applications) can be reduced to say 1 m, and there will also be significant advances in the depth of colour (from 16 bit to 24 bit to 32 bit and finally 42 bit depth) and that significant fine-tuning will take place in evaluation of remote sensed images.

The evaluation of images (at present largely dependant on the training of specialists) will to a much larger extent be aided by software (in part aided by the greater colour depth). This will allow for finer differences to be seen, as one can set different graduations for different purposes.

7.2 Development of the IT Industry affecting Precision Farming

7.2.1 Current Technology

Currently available are three mainstream operating systems (MAC™, Windows™ and Linux) with at this stage a variety of different software applications. Most of these are centred on specific requirements such as cropping, livestock or milk production to name a few (Agrocom website, http://www.Agrocom.com). Most of these programs are designed to run on a stand-alone basis on one of the mainstream operating systems. They are usually fairly straightforward to use, and, if correctly set up, require little support.

On the other side, comprehensive Geographic Information Systems (GIS) are available. These systems are often customised to suit the application and its requirements. It takes often some years to develop a specific system, such as a Pavement Management System (VKE, 2000). These systems also require significant upkeep, and often more than one person is working full-time on the system. For example, the PWV Consortium has full-time GIS operators to update and maintain data (VKE, 2001). These systems are expensive, have very long training period (often several months) and require significant computing resources.

It is the authors understanding that the professional versions of current yield mapping software are somewhere between the two systems described above (Böttinger, 1998).

Also, the first systems are in place where queries can be run over the Internet, where remote computing power is utilised. In these systems, the query is sent to the remote server, it is processed utilising the remote server, and only the result is sent back to the users. Some of these systems are text-based, such as the results database from Cyclelab (http://www.cyclelab.com), whilst some are graphics implementation such as the catchment boundaries as depicted on the Department of Water Affairs and Forestry website (http://www-dwaf.pwv.gov.za).

7.2.2 Future Technology

Given that precision farming systems in the future will probably be very involved systems, getting data from numerous sources. Sources may include universities (results of research), seed companies, fertiliser companies, images from low-orbit satellites and many others. As all data will need to be interpreted, and some may span large areas (typical satellite images span some 250 000 ha), there seems to be some advantage to house some data in a central GIS.

Forbes (2001) is of the opinion that in future most data will be centrally stored in a large storage systems, off-site from the individual user, above that, users will only utilise complex software (and pay on a time basis) via remote access.

The author is of the opinion that systems will follow two distinct development lines, one for the small, less involved user, and one line for the large scale commercial users. Typically these systems may have the following attributes:

(a) Small-scale Individual User

For small-scale users it is envisaged that systems are developed which will interact closely with the existing cropping software, having links directly to the farms accounting system. These software systems will enable limited multi-layer query techniques, and have limited ability to process complex what-if scenarios.

This may create the impression that the small-scale user will be at a distinct disadvantage when compared to large-scale commercial users. However, one has to remember that these users often have a very detailed local knowledge of their fields, gained from years of working the ground on a daily basis. This knowledge will aid decisions, and may also make more advanced systems (for these users) redundant.

It seems that these systems will be utilised by most full-time commercial farmers, and it may be that the use will be enforced by relevant legislation. The Danish government has already taken first steps in this direction.

(b) Large scale Commercial Users

For large-scale commercial users, as they have very much less in-depth knowledge of their local field conditions, a different set of rules applies. These users may far more benefit from pursuing other, equally necessary work (such as hedging crops) then trying to fine-tune a precision farming system.

As less and less in-depth knowledge on a field basis is available, and as data volumes grow, it makes more sense to have access to a fully featured, high-end GIS-based decision support system. An expert will operate this system, in all probability. A part of this system will probably be off-site, such as all remote sensed images. These will be accessed via remote query techniques, either via dedicated lines, or more likely, via the Internet. As GIS usually has normal links to normal database files, links to accounting systems and other farm data are easy to establish.

U Lourens (1999) had, for Omnia, established parts of such a system, based on ArcInfo.

8. RECOMMENDATION FOR FURTHER WORK

Although there is a significant amount of work to be done until one can start implementing precision farming in South Africa on a large scale, it is the authors believe that the following approach may be the easiest to implement these systems.

8.1 Establishment of a Precision Farming Forum

It is the authors believe that an industry wide, overarching precision farming forum should be established. All players in the industry, from mechanisation side, supplier's side as well as end users should be represented on this forum.

The aim of this forum should be to initially inform end users on what has been done to date in South Africa, and to make the information available to all users. The aim must be to break down the barriers that prevent the implementation of precision farming.

As a secondary function, this forum should also function as an information conduit to developers of both hardware, and software overseas. This information may be vital for the developers, and avoid frustrations to deal with implementation that were not written with sometimes unique circumstances in mind. (One example is the windrowing of crops in the southern Cape, where two swathes of 9 m each are placed directly adjacent of each other, creating an effective width (for the combine) of 17 – 18 m, way beyond the size of any available header).

Another function of this forum could be to broker some research deals, on the basis here is a student, there is a farmer, and set some guidelines for participation for both farmers and universities.

8.2 Implementation of more Cost Effective DGPS System

The author found, in many discussions with individual farmers, and contractors that the present rates charged for DGPS correction signals are rather high. The may be a number of options to lower these cost. These may include:

- Gaining access to Eskom's DGPS systems, on a partnering basis;
- Arrange for a pool license system with the commercial suppliers;
- Approach (possibly with Eskom and Telkom) the CDSM to implement the RDS based system earlier, and volunteer assistance;

Whatever the case, this hindrance to enter precision farming must be solved in the least costly manner to all parties.

8.3 Equipping Contractors to gather Yield Maps

It may also be an option to equip a number of contractor's machines for precision farming; these then gather the results for use by the forum (and for university research work). At the same time the contractor will market the technology to all farmers where he harvests. If the farmer wants the data, he can access it for a nominal amount, this revenue should cover the contractor's additional cost.

Much of the author's data was gathered by a contractor in this way.

8.4 Keeping Contact with Manufacturers

All major manufacturers are based in either North America, or Europe. At times it can be challenging to keep some of the systems running, or to find faults. It will be in the local farming communities interest to invite representative from those companies to show them what has been done in South Africa. The aim should be to create an awareness of our farming circumstances, and our specific needs. The author found generally that the manufacturers could gain much from a good working relationship.

8.5 Conclusion

Every reasonable effort should be made by all affected and interested parties to make this technology work in South Africa. While the author is aware, that farming margins are very narrow, and under squeeze, this technology is utilised mainly in the US and Canada to lower production cost, and as such may influence profitability in South Africa.

Enough work has been done in South Africa to be a foundation to work from, mainly by fertiliser companies. Both U Lourens (1999) and H van Vuuren (1998) mentioned that there interest was no longer to sell as much fertiliser as possible, but to optimise on the use, to mutual benefit of the company and the farmer.

9. REFERENCES

Holtmann, W (1997), DIE NEUE GENERATION, Profi, 11/1997

Moore, M (1998a) A STRATEGY FOR BETTER CROP MANAGEMENT BASED ON YIELD MAPPING, AGCO Ltd, Banner Lane, Coventry, UK

Starck, P (1998), PERSONALCOMMUNICATION

Rüsch, P (1993), TEGNOLOGIE OORDRAG IN LANDBOU – 'n EVALUASIE, Unpublished report as part of B Eng (Hons) Agric

Claas (1998), CLAAS ACADEMY – COURSE OFFERED TO MFSA PERSONELL, by Dr Joachim Stiegemann

Moore, M (1998), PERSONAL COMMUNICATION – when discussing precision farming during his visit to SA

Lourens, A (1998/9), PERSONAL COMMUNICATION – when discussing the yield maps of his fields, Land 1 to 8, Appendix M

Tom Bourke (1999), NAMPO (1998), PERSONAL COMMUNICATION WITH FARMERS REGARDING GROUND WATER POLLUTION (Remark: The author is currently involved in a water supply scheme near Tom Bourke, where NO_3 pollution is severe – due to irrigation)

Evans, LT (1975) CROP PHYSIOLOGY, Cambridge University Press.

Massey Ferguson (1996) FIELDSTAR™ MASSEY FERGUSON PRECISION FARMING SYSTEM

Claas (undated) AGROCOM FUTURE FARMING

Lourens, U (1999) PERSONAL COMMUNICATION – when discussing the soil sampling done on the Reitz fields

Clay, DE et al (undated), SYSTEMATIC EVALUATION OF PRECISION FARMING SOIL SAMPLING REQUIREMENTS, Internet download

Muller, B (1998/9), PERSONAL COMMUNICATION – during a presentation to the Losdoring study group

Meyer, K-H (1999), PERSONAL COMMUNICATION

Amazone, (1997) AMASAT – DUAL APPLICATION TECHNIK, as introduced during the Agritechnica 1997

Bornman, K (1998) DEVELOPING AERIAL REMOTE SENSING FOR PRECISION FARMING PURPOSES USING A DIGITAL MULTISPECTRAL SENSOR, Maize June 1998

Osborne, P (1999) PERSONAL COMMUNICATION

Helm, C (1998) PERSONAL COMMUNICATION

Marquering, J (1997), PERSONAL COMMUNICATION – a LBS implementation document can be downloaded from the Dronningborg website

Muller, M & Rüsch, P (1998) PERSONAL EXPERIENCE WHEN INSTALLING AN ACT TO A CASE AXIAL FLOW COMBINE

Bellstedt, H (1999) PERSONAL COMMUNICATION

Price, A (1997) PERSONAL COMMUNICATION – when discussing the various implementations of DGPS systems

CDSM (2000), TrigNet – THE SOUTH AFRICAN NETWORK OF ACTIVE GPS BASE STATIONS, Chief Directorate: Survey and Mapping, Mowbray

Eskom Surveyor, (1997) PERSONAL COMMUNICATION – when checking infrastructure to be relocated for Injaka Dam

Smith, G (1997) PERSONAL COMMUNICATION – when introducing OmniStar

Position (1998), GPS AND GLONASS, Position published on behalf of the Survey and Mapping Suppliers Association

Van der Merwe, P (1999) PERSONAL COMMUNICATION

Du Toit, AJ, (1997) PERSONAL COMMUNICATION – when mapping the First Yieldmap

Massey Ferguson, (1995) YIELD MAPPING IN ACTION – A PRECTICAL REVIEW BY JOHN FENTON, A supplement to THE CUTTING EDGE, Autumn 1995

Standard Bank (1988), FINANSIERING EN DIE BOER, Standard Bank, Johannesburg

Wright, N (1999) PERSONAL COMMUNICATION – when discussing the work done with / for John Fenton

Rüsch, A (1985) PERSONAL COMMUNICATION

Botha, D (1998/9) PERSONAL COMMUNICATION

Rüsch, P (1999) INTERNAL MFSA REPORT ON AMAZONE EQUIPMENT

QOP 410, (1992) FOTOGRAMMETRIE NOTAS, University of Pretoria

VKE (2000/1) PERSONAL COMMUNICATION

Forbes, B (2001) PERSONAL COMMUNICATION – during an informal in-house training session

Van Vuuren, H (1998) PERSONAL COMMUNICATION

PRECISION FARMING:
THE USE OF TECHNOLOGY FOR MORE EFFICIENT PRODUCTION

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ABSTRACT

Precision Farming is by far the most exciting new agricultural technology developed during the past decade, and although technology transfer is especially difficult in agriculture for a number of reasons, this technology has survived its initial stages of implementation. Historically field boundaries were often along natural soil boundaries, leading to small fields, which were treated homogenously. As agricultural machinery was developed and grew ever larger, fields were often combined to allow for more efficient cultivation. As result, fields with varying properties were created resulting in inefficiencies. Precision Farming was developed to overcome this problem. In this paper some results of initial research undertaken in South Africa under a variety of circumstances will be shown.

Key words: Precision Farming, varying yields, efficient production.

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1. INTRODUCTION

Technology, defined by Galbraith (Walker, 1987) as ***the systematic application of scientific or other organised knowledge to practical tasks*** was instrumental in the making of precision farming.

Over the past 30 or so years farm machinery was perfected. Tractors were developed where the operator could work for hours on end in the comfort of a modern, noise dampened cabin, soil engaging implements were developed to cultivate the ground to a predefined depth, fertiliser spreaders and sprayers can deposit chemicals were they were needed most. Combine harvesters were developed which could harvest these crops at sub 1% losses in almost any terrain, or circumstances.

Somehow market forces, and technical innovation led to machinery sizes growing (as any sales statistic will demonstrate), and with the consolidation of farms leading to larger and larger farms and thus fields, this advance in technology created a new set of problems and challenges. This was because field boundaries which were drawn naturally along different soil types, disappeared (Moore, 1998)

In the early 1980’s (Moore, 1998a) research undertaken by Massey Ferguson UK, in collaboration with Dronningborg (the manufacturers of Massey Ferguson combines in Denmark) tried to proof differences in the yield across a field, and if, how large these differences were. This research directly led to precision farming as it is known today.

2. PRINCIPLES OF PRECISION FARMING

Precision Farming is a process where a large field is divided into a finite number of sub-fields, allowing variation of inputs in accordance with the data gathered. Ideally this will allow maximisation of return on investment, whilst minimising the associated risks and environmental damage. The German (Profi, 1998) term for precision farming, ‘Teilflächenwirtschaft’ is far more descriptive of this process.

Figure 1 illustrates the processes involved in the precision farming system (Massey Ferguson, 1996). From this diagram it is evident that a number of processes are needed to have a complete Precision Farming system.

2.1 Factors affecting yield

There are a number of factors, which determine the yield of a particular crop on a particular field, these are:

2.1.1 Weather (no control)

With a climate as variable as the South African one, and little predictability as to how the season will turn out, the weather may have a profound impact on both the quantity and quality of the yield. However, as input into the precision farming system, the climate can be analysed, and can be grouped into a number of possible typical seasons, for use in precision farming systems.

2.1.2 Soil (little or no control)

The farmer has only limited control over the soil, for example, he cannot change the inherent fertility of his soil such as the soil structure, likelihood of water logging, but he has some control over the fertility status he can achieve. For example, the farmer, for a particular field cannot choose if the soil is a Hutton or a Katspruit, but within limits, he can achieve a higher fertility status by conserving humus and correcting nutrient status.

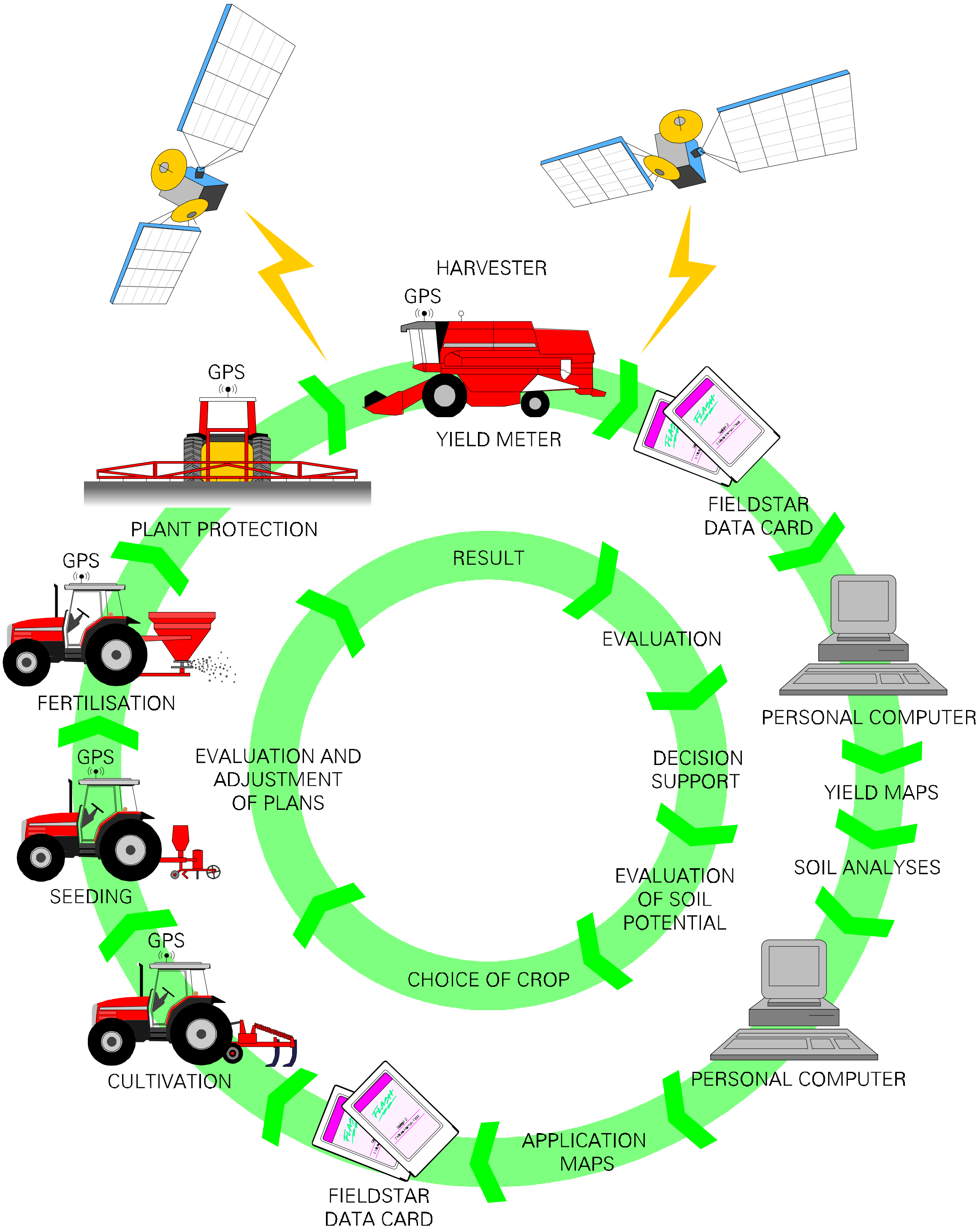


fig. 1: Precision Farming Circle

2.1.3 Husbandry (full control)

The farmer has full control over the husbandry of his crops. He can choose whatever he prefers to plant on his fields, and how he prefers to treat the individual crops for the conditions he may encounter. Although he is bound by inter-dependencies as to how he can treat the crops, these are known prior to committing a field to a particular crop. He has furthermore full control over the methods used, the timing and efficiencies of application.

2.1.4 Plant (full control)

The farmer has full control over his crop choices. He can choose between crop such as sunflower and maize, and for a particular crop he can also choose a particular variety suited to his particular circumstances. For a particular crop he can also choose row spacing, and intra-row spacing. He can also plan crop rotation to suit his overall farm management, and circumstances.

The interrelationship between these factors may be depicted as in figure 2, adapted from Moore, 1998:

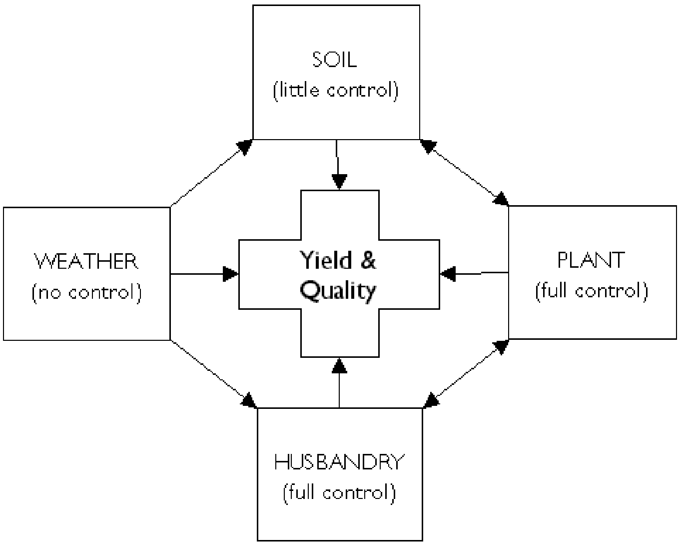


fig. 2: Factors affecting yield and quality

These interrelationships depict the influence these various factors have upon each other, e.g.:

- The plant chosen the previous season may have an influence on the fertility status of the soil, for follow on crops
- The weather of a particular season will have an influence on both the soil and the husbandry
- The husbandry may have an influence on the soil and plant for the next season

2.2 Factors affecting farming strategies

The farmer, when making decisions in his day to day running of the farm takes the above factors into account, as well as other influences on these decisions, such as:

- Personal Strategies (such maximum profit vs. maximum yield…)
- External influences (such political, estimated crops elsewhere, environmental, stocks, futures etc…)
- Local knowledge

A farmer who gathered information from his operation, related these to the weather patterns for a particular season, and taking pests and diseases into account, has been able to make fair predictions of the yield potential for a particular field in his given climatic conditions. He then utilised this predicted potential in combination with all of the above factors to work his fields. After another harvest the farmer readjusted the potential of a field.

In doing so the farmer treated every part of a particular field evenly, usually taking one or two soil samples per field per season to assist him in his decisions. Some farmers even treated whole farms (Free State Farmer, 1999) as one unit, even when fields were as far as 20 km apart, and most of the yield affecting factors differed widely.

He effectively ignored the in-field differences, even when he knew about them, because ***no technology existed to geo reference or to quantify these.*** This has, with the development of precision farming changed.

3. COMPONENTS OF A PRECISION FARMING SYSTEM

A precision farming systems has two types of components, the technical system needed to collect data and to apply inputs at a variable rate across a field. Typical technical parts are data loggers, a real time differentially corrected positioning system, measuring sensors, various job computers, as well as a user interface.

On European systems all these technical components work to a practical implementation of DIN 9684 (Marquering, 1997). This Code of Practice ensures compatibility of systems from various manufacturers. These systems are so-called open systems, as one is supposed to mix and match as required.

Some American systems were closed systems; these were therefore only compatible with machinery from the same manufacturer. This is however changing due to market forces (Stiegeman, 1998).

In a precision farming system, fields are divided into a large number sub-fields and it is now technically possible to take all the yield affecting as well as strategy affecting factors into account for each individual sub-field. Decision support systems were developed to address this part of the system, given a sub-field size of around 400 to 500 m².

These systems can be fairly simple (such as software usually supplied with the hardware) or can be fairly complex, GIS based support systems, such as one developed by a fertiliser company in South Africa (Lourens, 1999)

All decision support systems, simple or complex, have the same aim, that is to facilitate the 'what – iffing' by the farmer to find the optimal solution for his given set of strategic and yield affecting factors. This process can best be summarised in figure 3.

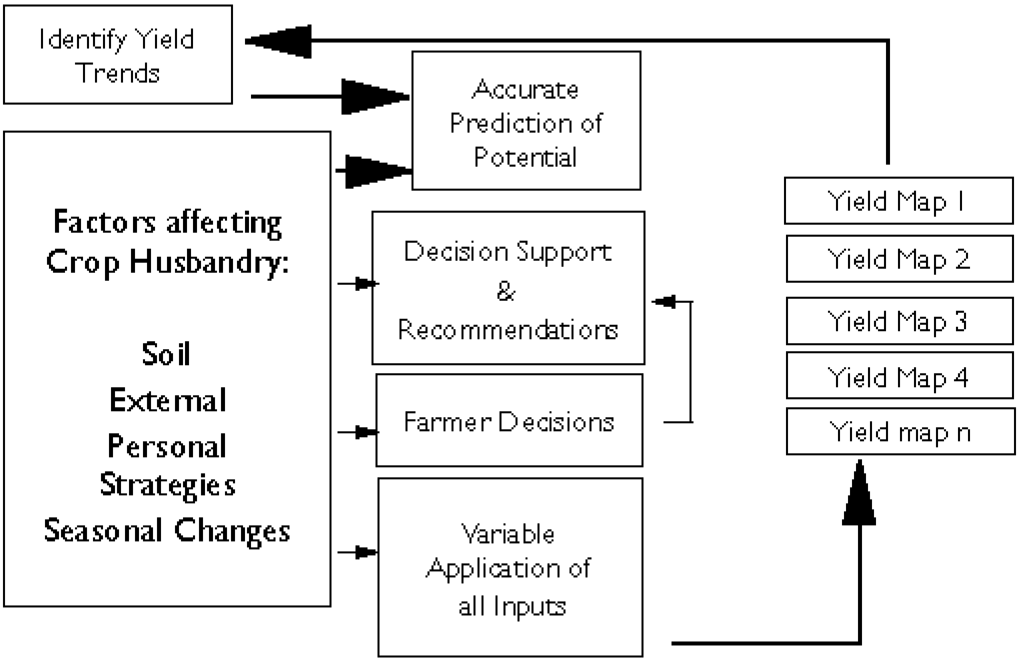


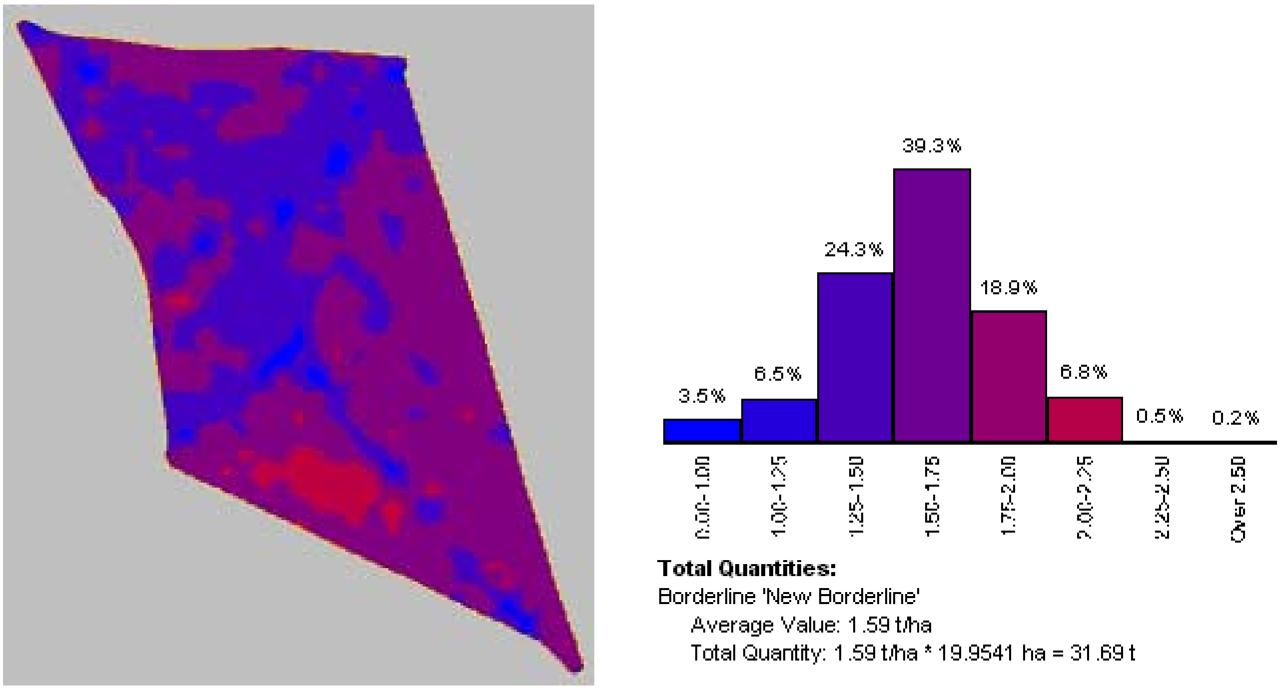
fig 3: Diagram showing decision making process

The important result is that the farmer does not follow a completely new process, but that he follows the principles he has derived over years, but only applies them to smaller sub-fields, instead of the larger, original field, or even the farm. He has now the tools to divide a field into the smaller units they were some time ago (especially in Europe), without introducing the physical boundaries, thus retaining economies of scale.

4. VARIABILITY OF YIELDS IN SOUTH AFRICA

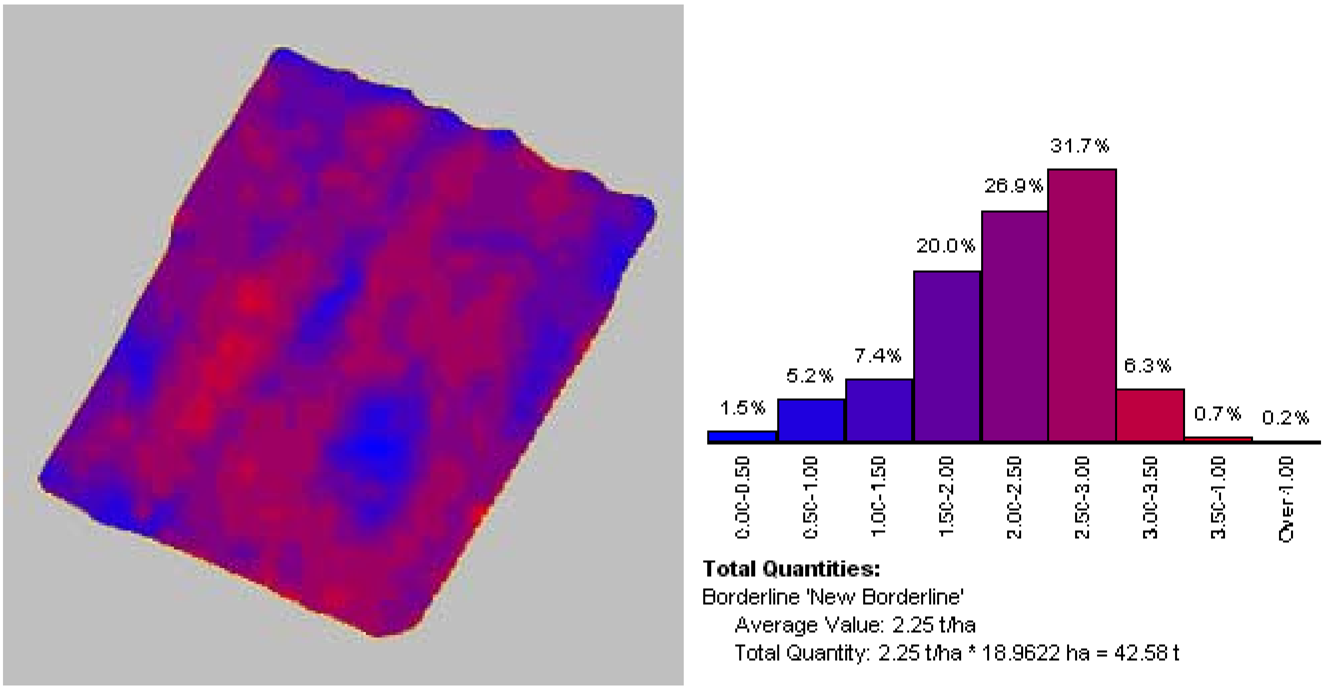
The author has over some 20 months collected data from a number of sites in South Africa. These are highly variable as the yield maps in figures 4-7 show. These yield maps were compiled between October 1997 (Canola, Swellendam, fig 4) and June 1999 (Maize, Reitz, fig 8). It may be noted that figures 6 & 7 are the same field in Reitz, and the differences in yield were 0.75t/ha on 15,2% of the field to over 6t/ha on 9,6% of the field (fig 6). The differences for maize in the same field are not as marked as for wheat. It is noteworthy that there is a correlation between the two maps, an encouraging result. The sunflower field from the Free State has been included to show the yield differences of a crop believed to be relatively resistant to drought.

Slightly less differences in yield occurred under irrigation, where Maize in 1998 (fig 8) and Wheat in 1998 (fig 9), both maps are from the same field in Hopetown.



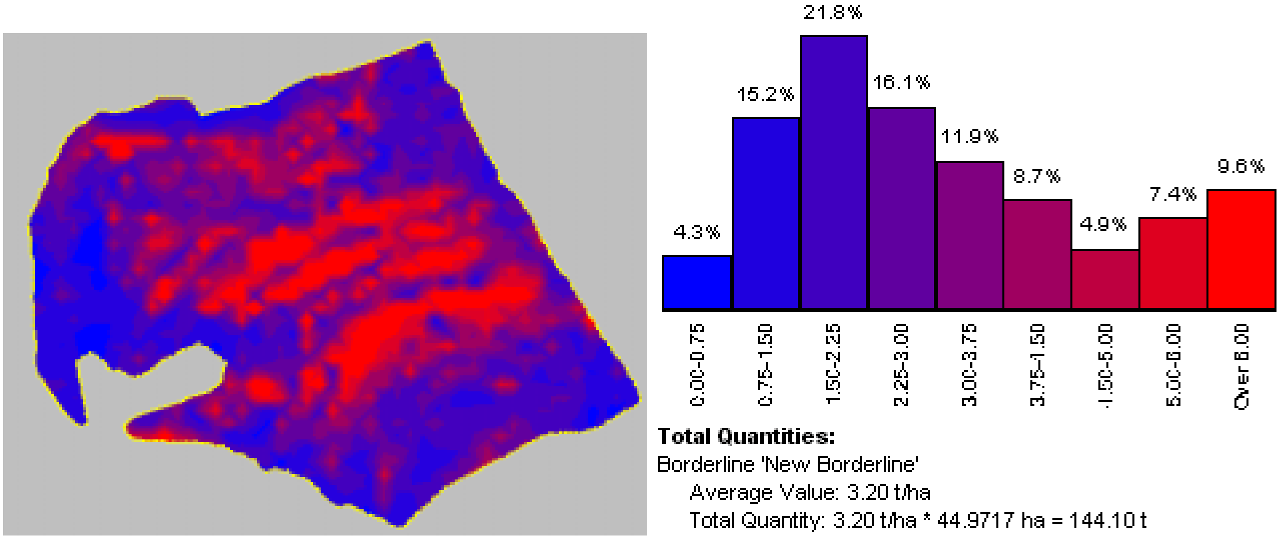
Total Quantities:
Borderline 'New Borderline'
Average Value: 1.59 t/ha
Total Quantity: 1.59 t/ha * 19.9541 ha = 31.69 t

fig 4: Canola (1997)



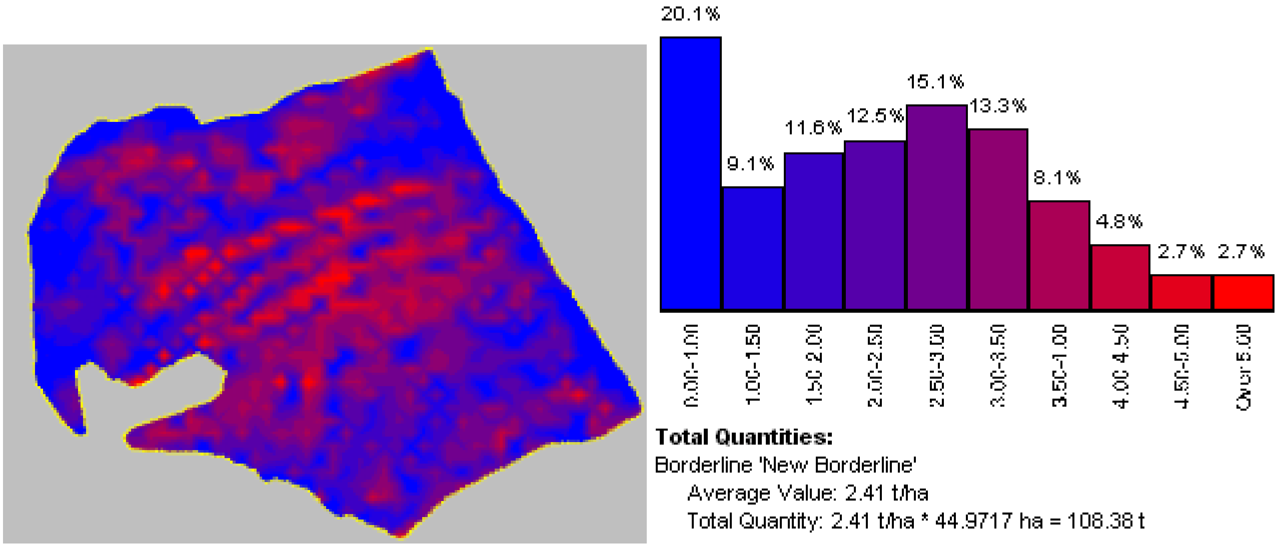
Total Quantities:
Borderline 'New Borderline'
Average Value: 2.25 t/ha
Total Quantity: 2.25 t/ha * 18.9622 ha = 42.58 t

fig 5: Sunflowers (1998)



Total Quantities:
Borderline 'New Borderline'
Average Value: 3.20 t/ha
Total Quantity: 3.20 t/ha * 44.9717 ha = 144.10 t

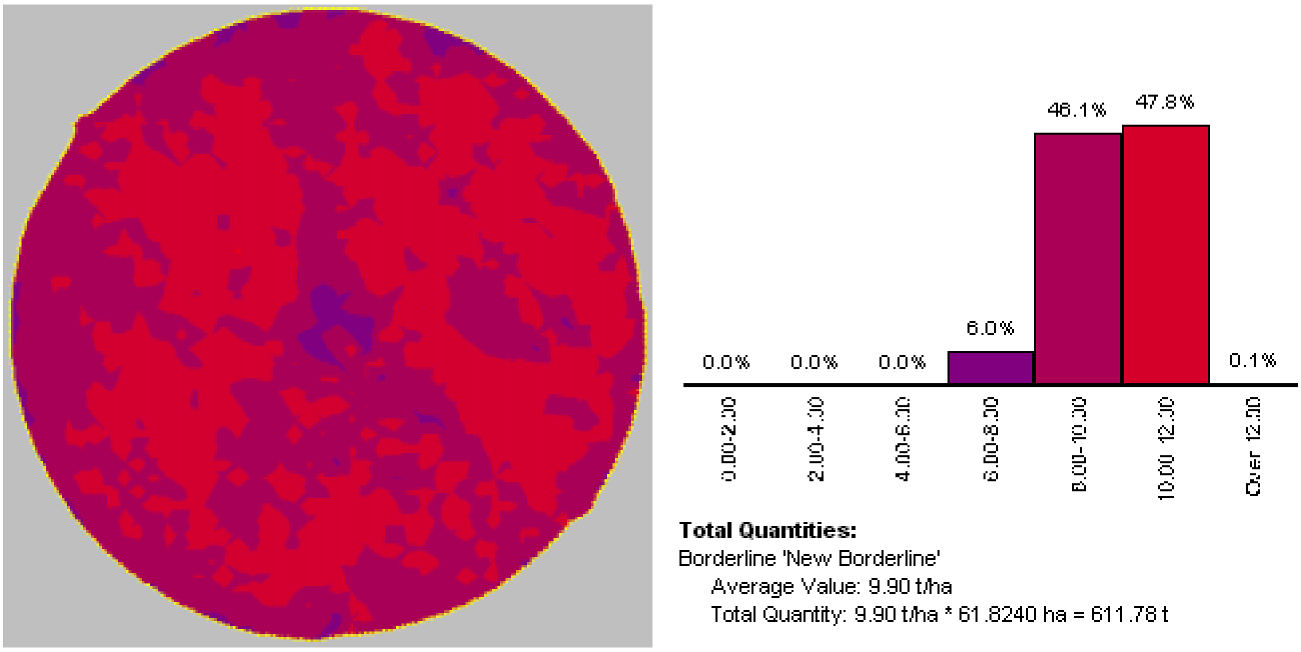
fig 6: Wheat (1998)



Total Quantities:
Borderline 'New Borderline'
Average Value: 2.41 t/ha
Total Quantity: 2.41 t/ha * 44.9717 ha = 108.38 t

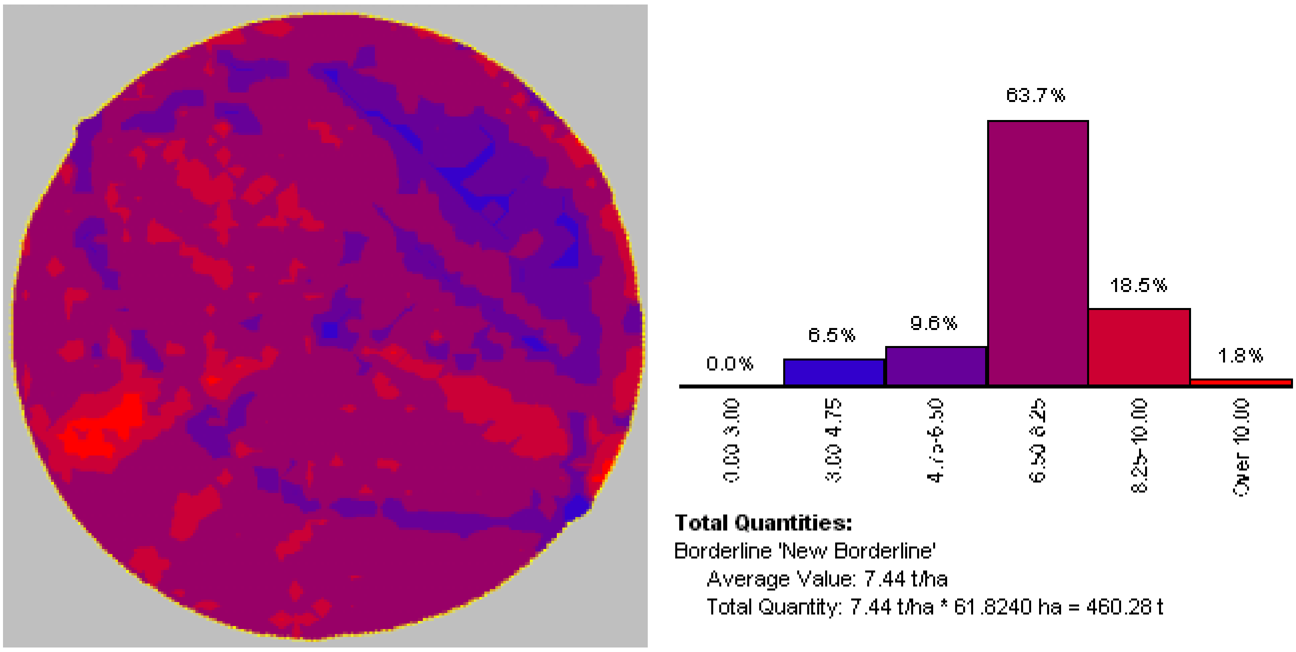
fig 7: Maize (1999)

Moore (1998) reports yield differences between 54% and 104% (based on the lower yield) in the United Kingdom. These results are not directly comparable to the ones obtained in South Africa, as there are other limiting factors applicable. The field mapped in the Reitz area has a highly variable soil depth, and as under the dry land conditions in South Africa moisture is most likely the limiting factor, this will have an influence on the yield. When discussing these maps with the farmer, and an agronomist from his fertiliser company the joint comment was: ‘ We are farming with water in this area.’



Total Quantities:
Borderline 'New Borderline'
Average Value: 9.90 t/ha
Total Quantity: 9.90 t/ha * 61.8240 ha = 611.78 t

fig 8: Maize Irrigation 1998



Total Quantities:
Borderline 'New Borderline'
Average Value: 7.44 t/ha
Total Quantity: 7.44 t/ha * 61.8240 ha = 460.28 t

fig 9: Wheat Irrigation 1998

Note that some low yielding areas in this field are due to a technical shortcoming.

A soil depth map for the field shown in figures 6 & 7 is shown as figure 10, and a typical nutrient map (P) is shown as figure 11

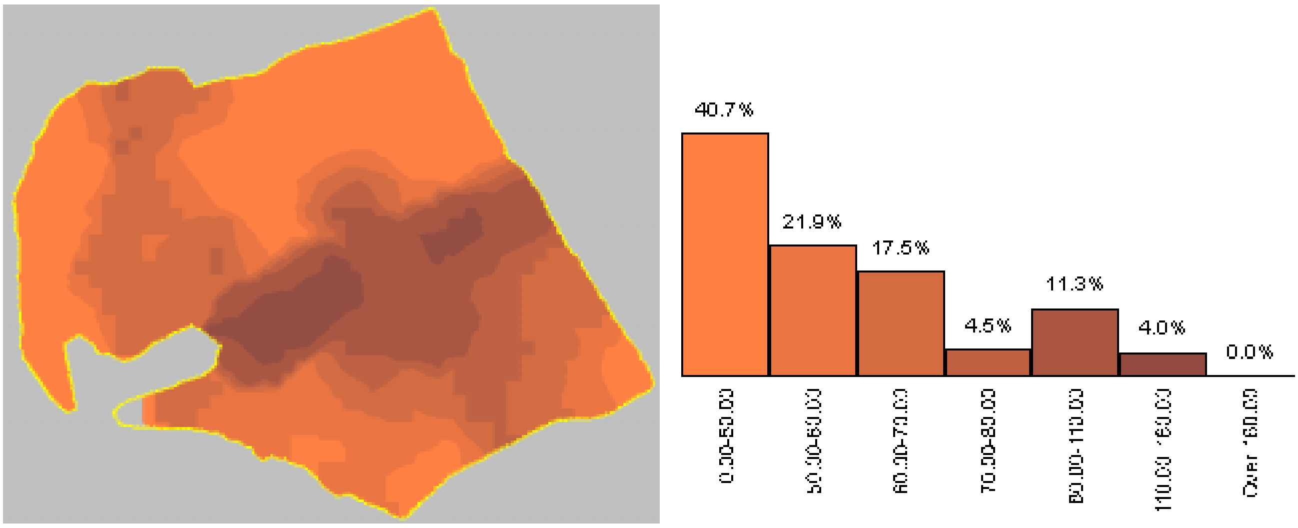


fig 10: Soil Depth

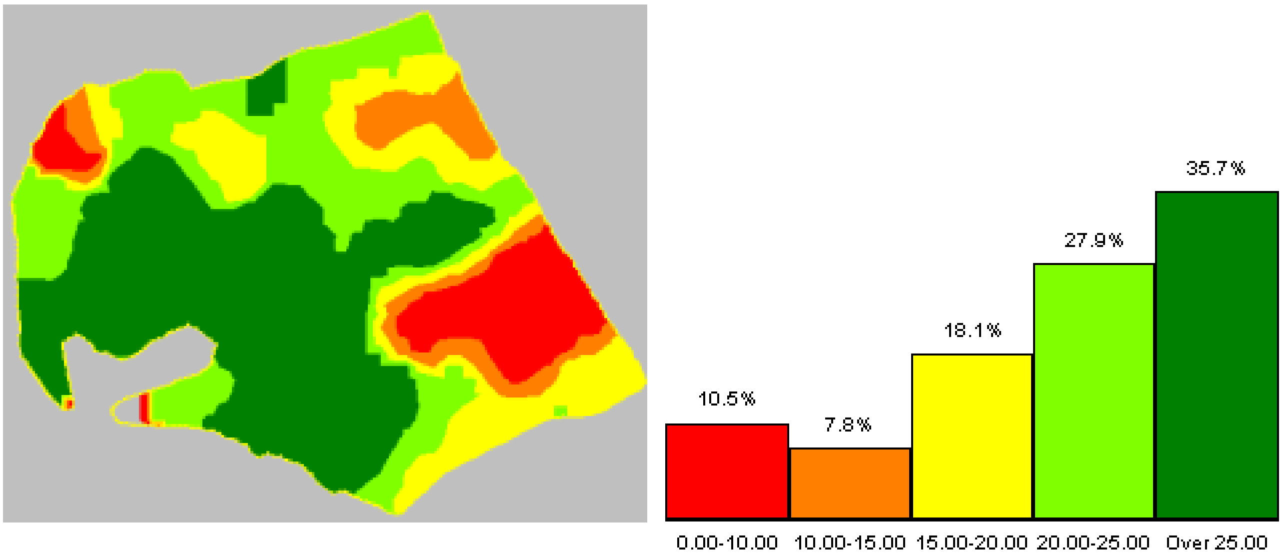


fig 11: P (1999)

The software on which this work was done, does not allow overlaying value maps for advanced queries, which can be typically done with a GIS system. A professional version is in the making.

As can be seen from the above examples, the yields on typical South African fields are highly variable, and that some nutrients vary as result quite dramatically over those fields.

5. FUTURE OF PRECISION FARMING

Agriculture has, in many parts of the world been under pressure from environmental groups to clean up its act. Part of this pressure is due to the fact that up to 30% of the applied Nitrogen (Tom Bourke, 1999) finds its way into our underground water. This percentage will depend largely on the soil conditions and the climatic conditions.

Precision Farming provides farmers with a tool to apply fertiliser according to the need of a particular sub-field, and no longer based on the average of the field. The savings made with this variable application can be fairly large. John Fenton (1995), a pioneer of this technology reports that his average Nitrogen application has been reduced from an average of 220kg/ha to an average of 160kg/ha, without affecting yield. As a result the amount N lost through leaching has been reduced by 60%. When reporting these savings, he was still treating his fields with the traditional blanket treatment method.

A farmer wishing to implement this technology will need to develop an implementation strategy to avoid disaster. Moore (1998) shows, that although there are fairly high yield variations in the UK, most parts of these fields still make a positive contribution to the income of the farm. This is in stark contrast to the conditions encountered in the variability of the wheat field in Reitz. On the field shown in figure 6 it was calculated that with input costs at 80% of the average yield, 55% of the field do not contribute, or even erode farm income. Even a minor reduction in input costs can increase profitability dramatically.

6. CONCLUSION: TECHNOLOGY ON THE HORIZON

This technology is certainly exciting, and is bound to change the face of agriculture in the long term. It will therefore either be implemented voluntary, or as it is happening in some European countries, by law.

The author is well aware of the hurdles presented by new technology, and especially in the case of precision farming the technology at its present stage is not for the faint hearted. Many a farmer has neither the interest nor the time to (Lourens, 1999; Osborne 1999) sit and study long manuals and do extensive analysis as to the best scenario.

It seems that some of the processes will move away from the farmer, to a service provider. This may be along the following lines:

- The farmer will collect the data, not limited to yield maps, but value maps, and forward these to his service provider.
- The service provider will in turn process these maps, and gather other relevant data for the area (such as remote sensing maps showing vigorousness of growth, or water stress), soil data, as well as results from soil sampling done.
- This data will be corrected and presented on a highly specialised GIS system, with simplified user interfaces. This GIS system will be at the service provider.
- The user can then interrogate his value maps, together with other 'public' information from his own computer, using the internet and an appropriate frontend such as ArcExplorer. He can then query a number of maps for a common purpose.

This will enable the farmer to use the technology without getting deeply involved in highly specialised GIS applications.

References:

Moore, Mark: A Strategy For Better Crop Management Based On Yield Mapping, AGCO Ltd, Coventry, England 1998

Moore, Mark (AGCO Ltd, Coventry, England): Personal Communication 1998a

Profi: Es läuft, aber mehr eckig als rund, Profi, January 1998

Massey Ferguson: Fieldstar ™ Massey Ferguson Precision Farming System, AGCO Ltd, 1996

Free State Farmer: Personal Communication, 1999

Marquering, Johannes (Amazone, Hasbergen, Germany): Teilflächenspezifische Düngerausbringung: Intelligente Verknüpfung von Betriebsdaten und Gerätespezifischen Technologien, Landtechnik, April 97 (2/97)

Stiegeman, Joachim (Claas Academy, Germany): Personal Communication, 1998

Lourens, Uys (Omnia Fertiliser, SA): Personal Communication, 1999

Tom Bourke: Lecture Presented to the Tom Bourke Study Group, 1999

Lourens, Anthoon (Farmer: Reitz) & Osborne, Pierre (Farmer: Hopetown): Personal Communication, 1999

Walker, Derek: Great Engineers, Academy Editions, London, 1987