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A decision support model for the adoption of precision agriculture practices

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ABSTRACT
The main objective of the study is to investigate the impact of Precision Agriculture practices on the margin and risk of a farming enterprise and the combination of enterprises as a whole-farm business in comparison to Conventional Farming. The procedures that were used to achieve the objective firstly included the scanning of the fields with the Gamma-ray spectrometer for identification of different management zone according to the variation in the physical soil properties and secondly the development of a decision support model namely the SPARÉ Model to investigate the impact of precision agriculture practices on the margin and risk of a farming enterprise and the combination of enterprises as a whole-farm business. The results of the study indicated that precision agriculture can be used strategically to reduce cost and increase productivity, thus increasing profitability.

KEYWORDS: Precision Agriculture; Decision Support Model; Management zone identification

1. Introduction and background

Precision agriculture (PA) is the use of different available technologies to optimize agriculture productivity by improving management of variability. There is a wide range of technologies that can be utilized to manage site-specific areas within a field. The adoption of these technologies is based on the farm scale, meaning that the level at which it become more cost-effective for a farmer depends on the cost savings for a farm, field or different management zones multiplied by the area (Bootle, 2001).

It is a simple task to calculate an enterprise budget for a certain crop under conventional farming (CF) practices, but it is more challenging to calculate enterprise budgets for different management zones and to calculate and evaluate the most profitable situation for a specific farm or field. This is where the need occurred to develop a model to help plan, analyse and evaluate two different scenarios for a specific farm and/or field. The large amount of variables, such as different crops, management practices, mechanisation technologies, variable rate irrigation (VRI) and variable rate applications (VRA), which must be considered for PA, raised the need for a decision support model (DSM).

A multidisciplinary approach is needed for agricultural scenario planning, analysis and evaluation of profitability and risk. There must be a combined focus on the following aspects namely, agricultural economics, agricultural mechanisation and agronomic principles. A farming operation is based on all above mentioned aspects and the interaction between them, but at the end the ultimate goal is to achieve financial stability and sustainability of natural resources.

The main objective of the study is to investigate the impact of PA practices on the margin and risk of a farming enterprise and the combination of enterprises as a whole-farm business in comparison to CF. The sub objectives are firstly to identifying management zones according to variation in physical soil properties and secondly to develop a DSM to evaluate the impact of PA practices on an individual farm enterprises and the farm business as a whole. The margin and production efficiency is respectively measured with the use of the gross margin (GM) and the operating profit margin (OPM) ratio.

The study is based on an irrigation fields situated on the western side of the Orange River in the Northern Cape, South Africa. The study fields are situated on the 29° S latitude and 24° W longitude, at an altitude of 1024 meters above sea level. The farm produces mainly maize, soybeans and wheat. Currently a CF approach is followed where all the inputs (irrigation, fertilizer and amelioration products) are uniformly applied over the entire field per crop. The input data that is used in the study/model were obtained from harvest monitor data, irrigation scheduling data, physical and chemical soil analysis and historic data obtained from the farmer. The six fields, as presented in Figure 1, that are used in the study covers a total area of 181.95 hectares with an average of 30.32 hectares per field.

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Figure 1: Layout of fields used in the study

2. Precision agriculture

Precision agriculture (PA) is a broad concept that has various definitions, but it can be described as a catch-all term for techniques, technologies and management strategies that address in-field variability. It focuses on development of integrated information and production systems that manage variability to optimize long-term, site specific and whole-farm productivity and it also minimizes the impact on the environment and natural resources.

Site Specific Management (SSM) is the core concept of precision agriculture. SSM is defined by Lowenberg-DeBoer and Swinton (1997) as the ''*electronic monitoring and control applied to data collection, information processing and decision support for the temporal and spatial allocation of inputs for crop production.*'' A specific area with its own properties must be locatable to be managed according to a specific manner particular to its requirements to achieve optimum production (Bootle, 2001).

Investment cost is another aspect that must be considered with PA. The total fixed cost of CF is lower than with PA, but with PA the additional benefits are increased production and decreased variable costs (Silva *et al*., 2007). With PA the investment cost in terms of equipment are more expensive, for instance with the adaption of uniform irrigation to variable rate irrigation (VRI) and uniform rate spreaders and planters to variable rate application (VRA).

Management zone identification

The identification of management zones is another core aspect in PA. Stable management zones can be described as zones that are temporal stable in regards to responsiveness of yield and quality to different treatments. It is thus important to cost effectively identify these zones for differential zone management (Sylvester-Bradley *et al*., 1999).

When these management zones are identified and located, the inputs like plant population, fertilizer, amelioration products, mechanisation, chemical products, irrigation and other variable costs can be manage accordingly. With variable rate application (VRA) the correct amount of resources can be applied on a specific area that will reduce nutrient loss and waste of natural resources like water (Maine, 2006). It will also help to reduce the occurrence of on- and off-site pollution.

Management zones can be identified with the use of different approaches. The methods vary from soil type, soil texture, soil depth, precipitation, a combination of all and spatial variation in crop yield characteristics and Steven *et al*. (1997) suggested the use of multi-year yield maps. Accuracy and cost issues with the above mentioned methods raised the need for a remote sensing method to do in-situ measurements.

A Gamma-ray spectrometer was used in the study to take the measurements for management zone identification. Based on the spectral measurements the sampling locations are selected and soil samples are taken. The spectral measurements at the sampling locations are used to correlate the spectral data to soil properties using the physical soil analysis results of the soil samples. The correlations found in the data are used to create soil property maps that are used to variably apply irrigation to the different management zones with the use of the following concepts.

Variable rate irrigation

Variable rate irrigation (VRI) is an innovative technology that enables a centre pivot irrigation system to optimize irrigation application (Almas *et al.*, 2003). For the purpose of the study the plant available water (PAW), infiltration rate and crop water usage, shown respectively in Figures 2, 3 and 4, is used to calculate and plan the irrigation scheduling program for the different management zones. The following factors must also be considered namely; the capacity and efficiency of the irrigation system, topography of the field and the scheduling principles for optimum plant production. Sadler *et al.* (2005) found that VRI can reduce the total irrigation water usage with between 8 – 20%.

3. Decision support model

Decision support model (DSM) is broadly defined by Finlay (1994) as ''*a computer based model supporting the*

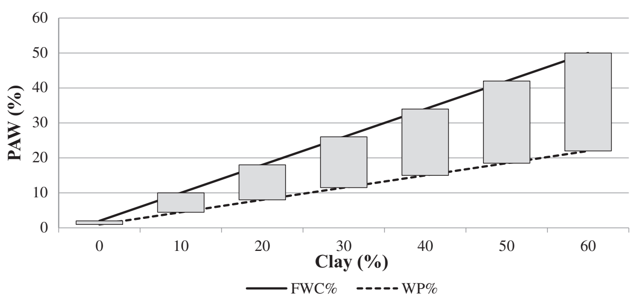

Figure 2: Plant available water capacities for different soils by clay content

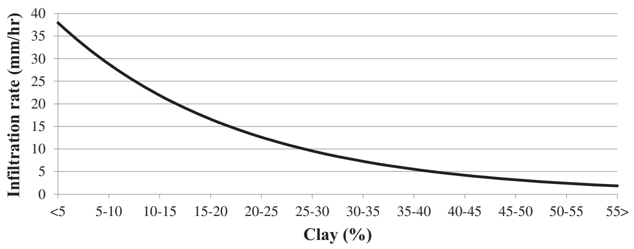

Figure 3: Infiltration rate for different soils by clay contents

decision making process". The emphases of the DSM must be on supporting a certain decision in regards to a problem and not necessarily providing an answer. It must enable the farmer to base his/her decision on certain outcomes of different potential courses of action, thus different scenarios. These scenarios can be based on economic, environmental and social factors that may influence a specific choice or outcome.

Precision crop management (PCM) are also important when designing and planning a DSM. PCM can be defined as a multi-objective decision-making process that must incorporate a diversity of data, opinions, preferences and objectives (Jones *et al*., 2000). This will help to incorporate different aspects in one model with the necessary alternatives for possible variability.

4. Procedures

Management zone identification

Figure 5 shows the correlations according to the Count Rate (Bq/kg) for the soil properties from the measurements obtain by the Gamma-ray spectrometer. The regression values that were respectively obtained for clay, silt and sand was $R^2 = 0.97$, $R^2 = 0.81$ and $R^2 = 0.92$. The formulas obtained from the correlations are then used in a PAW model to extrapolate the specific property values to all the Gamma-ray spectrometer readings.

The plant available water (PAW) in millimetre is calculated as:

$$PAW = FWC - WP \tag{1}$$

where

FWC Field water capacity in millimetre as calculated

WP Wilting point in millimetre as calculated

After the calculation, interpolation and mapping of the PAW to the specific field boundaries with the use of Spatial Management Systems (SMS) software, the management zones for SSM can be defined. The physical and chemical properties of the soil can then be classified into the specific management zones. After identification of the management zones the variable rate irrigation

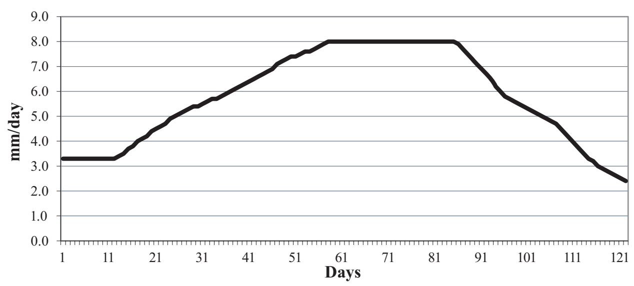

Figure 4: Daily crop water usage demand of maize

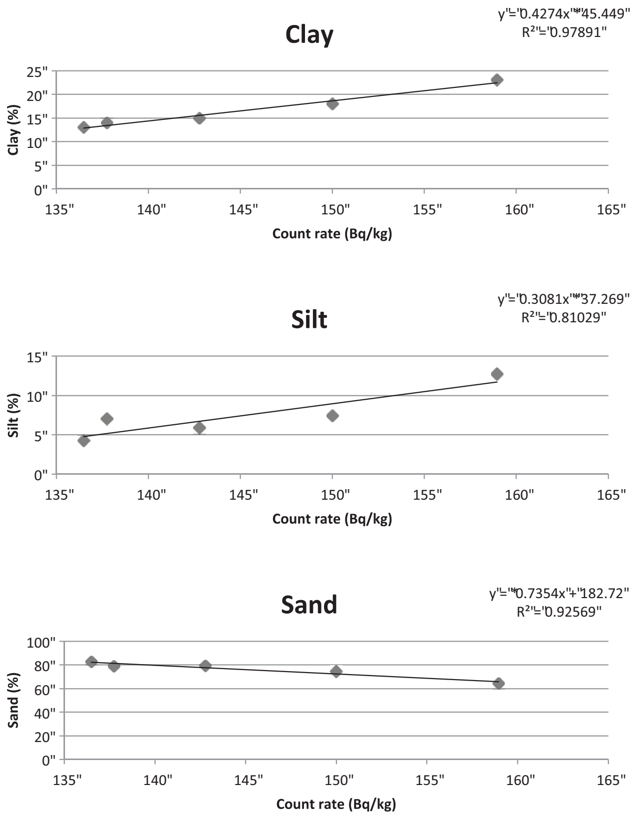

Figure 5: Regression curves showing the correlation between the physical soil properties and Gamma-ray spectrometer measurements

(VRI) and variable rate application (VRA) of fertilizer and amelioration products can be planned in accordance to the crop yield potential of the specific management zone.

Decision support model

The SPARÉ Model (Scenario Planning, Analysis and Risk Evaluation) is designed to plan and evaluate two different scenarios under irrigation and/or dry land conditions with the use of multiple enterprise budgets per management zone and different crops per annual production cycle. There are certain designated sheets for the different production inputs for instance; fertilizer, lime and gypsum, mechanization costs, chemical products and water and electricity. These inputs can be changed per region, farm, season, etc. and the same cost is used for calculations in both scenarios.

The first step of the model is to use the different management zone areas and plan the farming operation accordingly. The initial farm planning consists of rotational crop planning per management zone per season for irrigation and/or dry land according to a percentage of available area. After the initial planning is completed, individual crop enterprise planning must be done per management zone. This planning proses consist of the following variables per zone namely; seeding, fertilizer, ameliorants, mechanization, water demand and management, chemical products and other costs. The following variable costs are taken into consideration to calculate and plan the whole farm business and each crop - and management zone enterprise individually. The variable costs consist of seed, fertilizer, ameliorants,

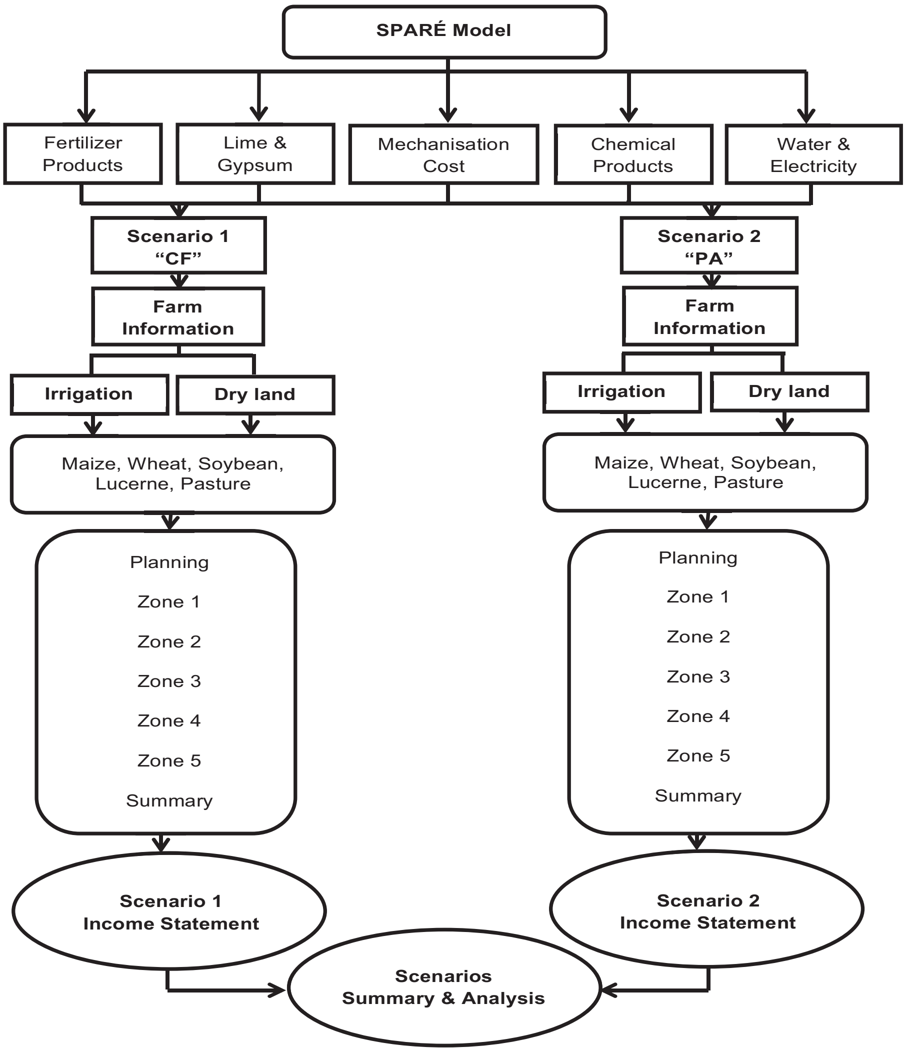

Figure 6: Schematic representation of the SPARÉ Model

mechanization, herbicides, pesticides, insurance, irrigation, transport, marketing, other variable costs and interest on operating capital. All these cost is taken into account to calculate the impact on each enterprise in accordance to the whole-farm operation.

The model's structure are described in Figure 6 which shows the overview of the model as a whole from farm information, management zone planning, enterprise planning, and enterprise budgets to the farm income summary, evaluation and analysis.

The values that are used in the model are shown in Table 1 and margin-, income-, cost- and analytical values are included[3]. All calculations start from management zone level, then enterprises level to whole-farm level. The gross margin (GM) of the scenario (SC) is the final answer in regards to profitability and is calculated as:

$$GM_{SC} = GI_{SC} - TVC_{SC} \quad (2)$$

where

GI Gross income (R)

TVC Total variable cost (R)

The total income of all the management zones give the sum of the specific enterprise and the total of the enterprises give the sum for the specific scenario. The gross income (GI) of a scenario (SC) is calculated as:

$$GI_{SC} = GI_{E(Ia+Ib+Ic+Id+Da+Db+Dc+Dd)} \quad (3)$$

where

$_E$ Enterprise

$_{I\#}$ Irrigation enterprise where # represents enterprise (a – d)

$_{D\#}$ Dry land enterprise where # represents enterprise (a – d)

The cost calculations consists of variable cost and it is the part of the total cost component that could vary within the framework of a specific production structure as the size of the enterprise varies and/or the intensity of the production per unit changes. The total variable cost (TVC) of a scenario (SC) is calculated as:

$$TVC_{SC} = TVC_{E(Ia+Ib+Ic+Id+Da+Db+Dc+Dd)} \quad (4)$$

Financial analysis pertains not only to income and expenditure, but also to the ability to meet financial liabilities, carry risk and strategically utilise available capital. The breakeven price and yield is simple calculations that can be used to calculate the minimum price and yield that must be achieved for a specific management zone or enterprise to be profitable. The operating profit margin ratio is used to measure the operating efficiency of a farm business and it is

[3] All calculations and formulas are available on request from author.

usually written in percentage. The operating profit margin (OPM) for the enterprise (E) is calculated as:

$$OPM = (GM_E/GI_E)\% \quad (5)$$

5. Results

Management zones

The PAW (in millimetres) of the fields is shown in Figure 7. The field's clay percentages vary between 5% and 30% and the PAW varies between 35 millimetres to above 50 millimetres. The infiltration rate are directly correlated with the clay percentage and it varies between 25 mm hr^{-1} to as low as 8 mm hr^{-1}. From the variation in spatial PAW data, five management zones in pie slice-shaped sectors are identified. The management zones (sectors) differ in sacraments of five from below 35 millimetres to above 50 millimetres. The zones are respectively 13.9, 47.8, 47.1, 57.3 and 15.6 hectares. These management zones are used in the decision support model for the PA calculations.

Decision support model

Figure 8 presents the total income from different enterprises for PA and CF. It is evident from Figure 8 that the total income generated with PA is more than with CF for all the enterprises. The average increase in income from PA for all the enterprises is 9.6%. The individual income of maize, wheat and soybean is respectively 8%, 13% and 8%. The reason for the higher income for wheat is because no sampling or amelioration has been done during the wheat season.

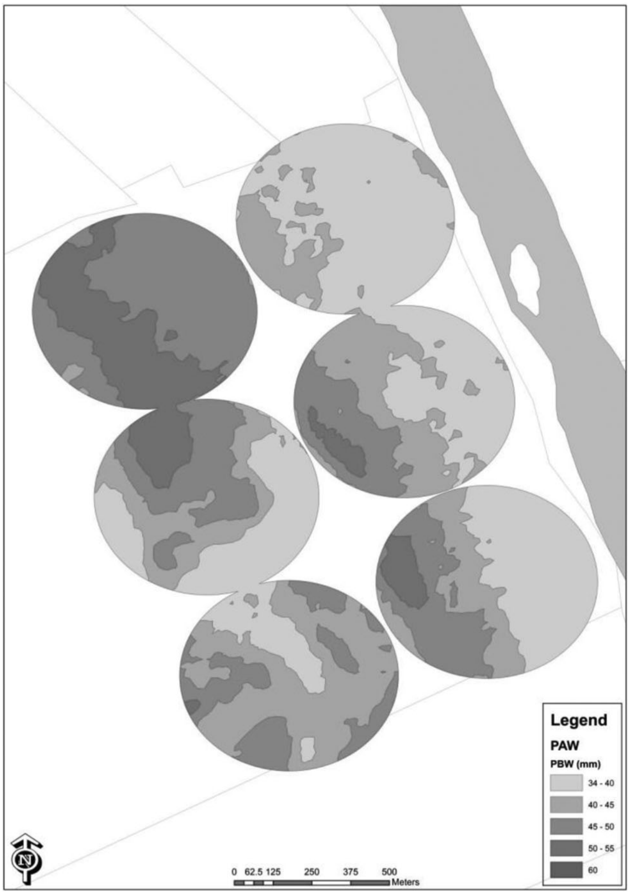

Figure 7: Plant available water map of the study fields

Figure 8: Total income for different enterprises according to CF and PA

In the model all the inputs as shown in Table 1 is used for the calculation of the TVC of the two scenarios. The difference in TVC of PA to CF can be seen in Figure 9, with only the inputs that varies between PA and CF is shown in the figure.

From Figure 9 it is evident that the largest difference in cost is with total other variable cost (TOVC). The TOVC of PA is 282.8% higher than CF, because of grid samples that were taken, the scanning of the soil for physical soil variations, the use of a spreader contractor for application of amelioration products and the cost involved for adapting the irrigation system to VRI. Although the higher cost of TOVC, it only represents 3% of the TVC of all enterprises.

It must be taken into account that it is only necessary to take grid samples every three years for VRA purposes, because the chemical soil properties will only change significantly over that period of time due to management practices. This will lead to a lower TOVC in the seasons that follow. In regards to the management zone identification the cost is once-off, because the physical soil properties does not change over a short period of time. The cost of adaption to VRI technologies is calculated per season per hectare over a period of 5 years. It is found that the useful life of these technologies is between 5 to 10 years (Bootle, 2001).

According to the total amelioration product cost a 31.3% saving is made with gypsum and 0.7% saving in regards to fertilizer for PA. Although only 0.7% less amelioration fertilizer is used, it must be taken into account that the application of the fertilizer is site-specific in accordance to the inefficiency of the soil's chemical properties and that leads to higher efficiency of applied product. When looking at the amelioration fertilizer of the individual enterprises, the cost of maize is 1.2% higher and soybeans 2.5% lower. This only shows that a saving is not necessarily made, but the product is more effectively applied.

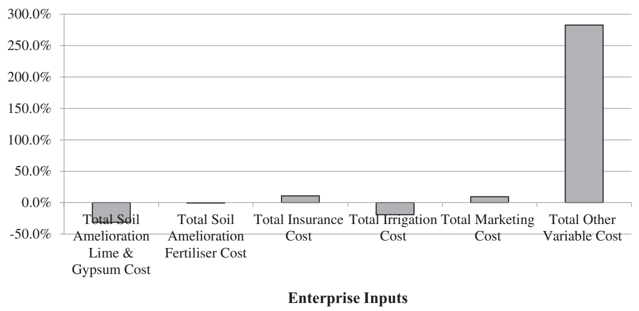

Figure 9: Percentage variation between input costs of PA and CF

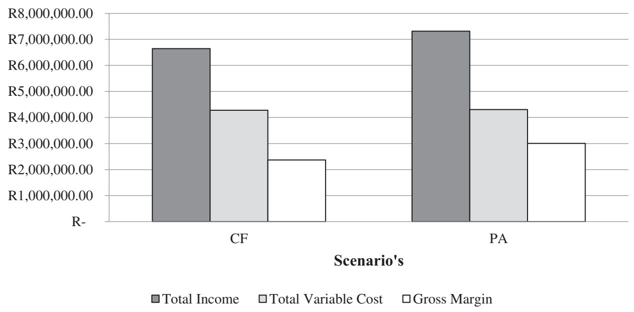

Figure 10: Summary of total income, total variable cost and gross margin of CF and PA

The total cost of irrigation is 19.2% lower with PA than CF, the saving occurred from the efficient application of irrigation water. Although the same amount of irrigation is applied over the field according to the crop water demand, the different management zones is managed in accordance to each zones measured properties namely, PAW and infiltration rate. A further benefit is that less nutrient losses occurs due to leaching and that leads to lower on- and off-site pollution.

Analysis and evaluation

In Figure 10 the Total Income, Total Variable Cost and Gross Margin are shown for CF and PA respectively. For PA the TI is 10% higher and the TVC is 0.7% higher than compared to CF, while the GM is 26.9% higher for PA than for CF. When looking at the OPM it is 36% and 41% respectively for CF and PA. It is thus 5% higher in the case of PA, making PA more profitable than CF. It also means that PA has a better return on investment (ROI) than CF for each Rand spend.

Comparing the individual enterprises according to CF and PA practices it is evident that PA is more profitable than CF. The GM for maize, wheat and soybeans are respectively 22.3%, 27% and 36.2% higher for PA than for CF. The OPM of CF and PA for maize is 32% and 37% respectively, for wheat it is 48% and 54% respectively and for soybeans it is 20% and 27% respectively.

From all these figures it is evident that PA practices is more profitable than CF with the correct ratio of in-field variation. It can also be seen that from all the enterprises soybeans is the most profitable crop, but wheat has the highest OPM.

6. Conclusion

The objectives of the study were twofold. The main objective of the study was to investigate the impact of PA practices on the margin and risk of a farming enterprise and the combination of enterprises as a whole-farm business in comparison to CF. The sub objectives were firstly to identifying management zones according to variation in physical soil properties and secondly to develop a DSM to evaluate the impact of PA practices on an individual farm enterprises and the farm business as a whole. The margin and production efficiency was respectively measured with the use of gross margin (GM) and operating profit margin ratio (OPM).

The procedures that were used in the study included the scanning of the fields with the Gamma-ray spectrometer for identification of different management zone according to the variation in the physical soil properties. Secondly a DSM was designed namely the SPARÉ Model to investigate the impact of PA practices on the margin and risk of a farming enterprise and the combination of enterprises as a whole-farm business.

The results of the study indicated that PA can be used strategically to reduce cost and increase productivity, thus increasing profitability. In the study the total variable cost and total income of PA is respectively 0.7% less and 10% higher than with CF. There are an increase of 26.9% in gross margin for PA against CF. When looking at the operating profit margin ratio (OPM) it is 36% and 41% respectively for CF and PA. It is thus 5% higher in the case of PA, making PA more profitable than CF. It also reduces the impact of agriculture on the environment and natural resources.

It is found that the feasibility of PA practices depends on field variation, crop value, economics of scale and the useful life of the equipment. According to Maine (2002) "*PA has the potential to enhance profitability on South African soils, which are characterized by great variability in depth and fertility within given fields.*" Variable rate irrigation (VRI) will also become more important in the future to protect the scares water resources in South Africa and the world. The measuring of efficiency in agriculture will become more important and it can be defined as the relationship between output and input calculated as a ratio.

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