

# Applying a Decision Support Model to Investigate the Influence of Precision Agriculture Practices on Sustainable Crop Production

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**Abstract:** The concepts of precision agriculture (PA) and sustainability are inextricably linked. PA can be described as a catch-all term for techniques, technologies, and management strategies that address in-field variability. Sustainable agriculture, in short, strives to enhance environmental quality and the resource base on which agriculture depends. The main objective of the study is to investigate the impact of PA practices on the sustainability of a crop production enterprise in comparison with conventional farming (CF). The procedures that were used to achieve the objective included the scanning of fields with a gamma-ray spectrometer for the identification of management zones and the application of a decision support model, namely the Scenario Planning, Analysis and Risk Evaluation (SPARÉ) model, to investigate the impact of precision agriculture practices on sustainability. Three crops—maize, wheat, and soya beans—were used in the model to generate the results. The results of the study indicate that precision agriculture does enhance sustainability, as the amount of lime and gypsum, fertiliser, and water that are applied per ton of grain harvested decrease by 22.6%, 11.9%, and 24.1%, respectively, on average for the three crops, making the resource use more sustainable than with conventional agriculture. The gross margin of the whole farm scenario increased with 26.9% and, thus, increased the financial sustainability of the whole farm enterprise.

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## 1. Introduction

Sustainable agriculture has been defined in numerous different ways in the past, and it is especially due to the debated meaning of “sustainability” that different definitions exist [1–6]. Sustainable agriculture as a term is defined by the American Society of Agronomy as “the one that, over the long term, enhances environmental quality and the resource base on which agriculture depends; provides for basic human food and fibre needs; is economically viable; and enhances the quality of life for farmers and the society as a whole.” [7] (p. 15). According to the Sustainable Agriculture Initiative Platform, “sustainable agriculture is the efficient production of safe, high-quality agricultural products, in a way that protects and improves the natural environment, the social and economic conditions of farmers, their

employees and local communities and safeguards the health and welfare of all farmed species.” [8].

Sustainable agriculture is, therefore, the production of food and fibre in a way that the environmental, social, and economic dimensions are considered. The environmental dimension include issues such as climate change, energy, water scarcity, biodiversity, and soil degradation, while the social dimension is concerned with factors like labour rights, health of communities, accessibility and affordability of food, food quality and safety, as well as animal welfare. The economic dimension deals with productivity, efficiency, and competitiveness, where the benefits of these factors are not only noticed in farm profitability, but also in the rest of the value chain and will lead to thriving local economies [8].

According to Bongiovanni and Lowenberg-DeBoer [9], the concepts of precision agriculture (PA) and sustainability are inextricably linked. 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 focusses on the development of integrated information and production systems that manage variability to optimise long-term, site-specific, and whole-farm productivity, and it also minimises the impact on the environment and natural resources. The application of fertilisers and water only where and when they are needed should reduce environmental loading, while the production is also more efficient and thus results in lower input costs per unit of output to enhance profitability. There exists a wide range of technologies that can be utilised 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 they become more cost-effective for a farmer depends on the cost savings for a farm, field, or different management zones multiplied by the area [10].

### *1.1. Problem Statement and Objectives*

It is a simple task to calculate an enterprise budget and physical resource use for a certain crop under conventional farming (CF) practices, but it is more challenging to do so for different management zones and to calculate and evaluate the most sustainable practice for a particular farm or field. This is where the need arises to utilise a model that aids in the planning, analysis, and evaluation of two different scenarios for a particular 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, highlight the need for a decision support model (DSM).

The main objective of the study is to investigate the impact of PA practices on the sustainability of a crop production enterprise, and the combination of enterprises as a whole-farm business, in comparison to CF. The sub-objectives are, firstly, to identify management zones according to variation in physical soil properties and,

secondly, to apply a DSM to evaluate the impact of PA practices on an individual farm enterprise and the farming business as a whole.

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

## 2. Experimental Section

The study is based on irrigation fields situated on the western side of the Orange River in the Northern Cape Province of South Africa. The fields are situated on the 29° S latitude and 24° W longitude, at an altitude of 1024 m above sea level. The farm produces maize, soya beans, and wheat in a rotational system. 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 are used in the study were obtained from harvest monitor data, irrigation scheduling data, physical and chemical soil analysis, and historical data obtained from the farmer. The six fields that are used in the study cover a total area of 181.95 ha with an average of 30.32 ha per field.

### 2.1. Management Zone Identification

Management zones can be identified by using different approaches. The methods vary from soil type, soil texture, soil depth, precipitation, a combination of all these, and spatial variation in crop yield characteristics. Steven and Miller [11] suggest the use of multi-year yield maps. Accuracy and cost issues with the above-mentioned methods highlight the need for a remote sensing method to perform in situ measurements and a gamma-ray spectrometer (MS-1200 Type SBG932, Medusa Explorations: Groningen, Netherlands) was used in this study to take the measurements for management zone identification.

The correlations according to the count rate (Bq/kg) for the soil properties from the measurements obtained by the gamma-ray spectrometer are determined for clay, silt, and sand. The regression values that were respectively obtained for clay, silt, and sand were  $R^2 = 0.979$ ,  $R^2 = 0.810$ , and  $R^2 = 0.926$ . The formulas obtained from the correlations are then used in a plant available water (PAW) model to extrapolate the specific property values to all the gamma-ray spectrometer readings. The PAW (mm) is calculated as:

$$PAW = FWC - WP \quad (1)$$

where  $FWC$  is the field water capacity (mm), and  $W$  is the wilting point in (mm).

After the calculation, interpolation and mapping of the PAW to the particular field boundaries with the use of Spatial Management Systems (SMS) software (*SMS Advanced*, 14.50; Ag Leader Technologies: Ames, IA, USA; 2014), the management zones for SMS can be defined. The physical and chemical properties of the soil can then be classified into the specific management zones. The VRI and VRA of fertiliser and amelioration products can then be planned in accordance to the crop yield potential of the particular management zone.

## 2.2. Decision Support Model

Due to the different management zones, the large number of variables that must be considered in calculating the enterprise budget for PA highlights the need to use a decision support model. The term decision support model (DSM) is broadly defined by Finlay as “a computer-based model supporting the decision-making process” [12] (p. 1282). The emphases of the DSM should be on supporting a certain decision with regard 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.

The Scenario Planning, Analysis and Risk Evaluation (SPARÉ) model was designed in Microsoft Excel (*Microsoft Excel*, 2010; Microsoft: Redmond, WA, USA; 2010), 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 fertiliser, lime and gypsum, mechanisation 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 all scenarios [13].

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 should be done per management zone. This planning process consists of the following variables per zone: seeding, fertiliser, ameliorants, mechanisation, 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, fertiliser, ameliorants, mechanisation, herbicides, pesticides, insurance, irrigation, transport, marketing, other variable costs, and interest on operating capital. All of these costs are taken

into account to calculate the impact on each enterprise in accordance to the whole farm operation.

The model’s structure is described in Figure 1, which gives an overview of the model as a whole from farm information, management zone planning, enterprise planning, and enterprise budgets to farm income summary, evaluation, and analysis.

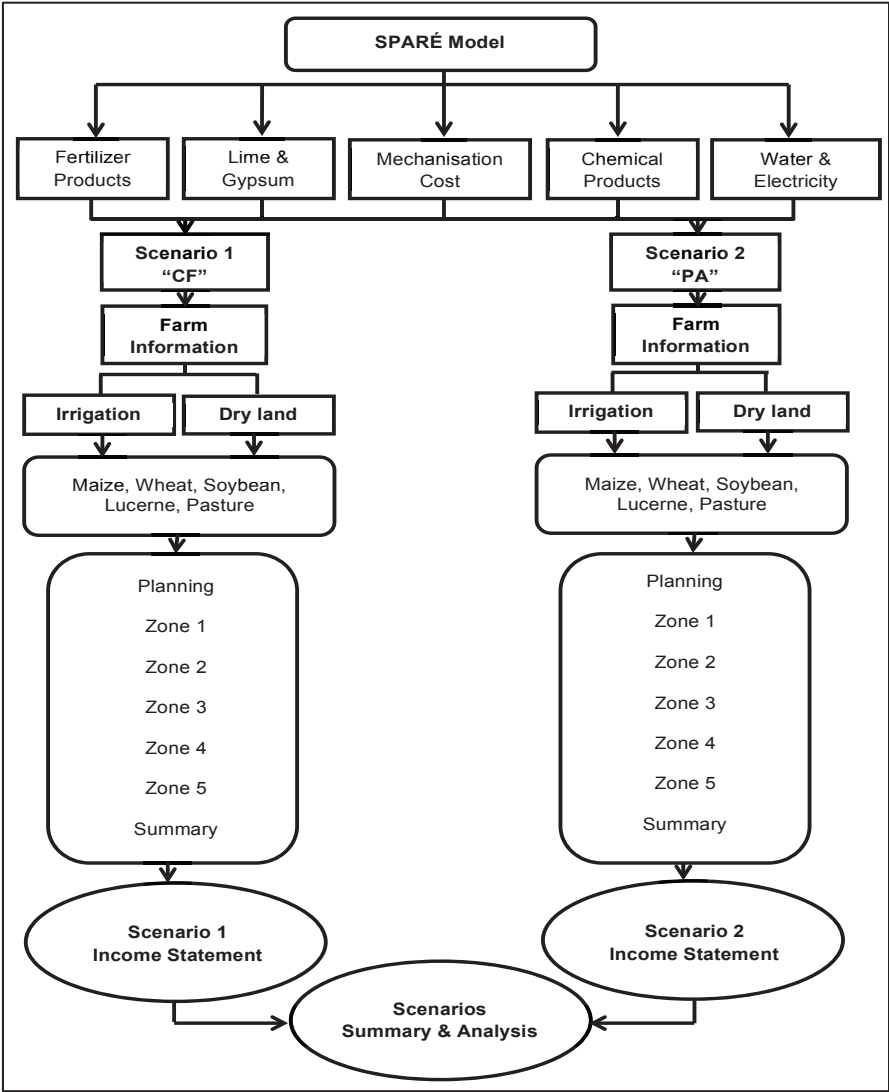


Figure 1. Schematic representation of the SPARÉ model.

All calculations start from management zone level, then the enterprise level to whole-farm level (all calculations and formulas are available from the authors upon request). The gross margin ( $GM$ ) of the scenario ( $SC$ ) is the final answer with regard to profitability and is calculated as:

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

where  $GI_{SC}$  is the gross income ( $GI$ ) of the scenario, and  $TVC_{SC}$  is the total variable cost ( $TVC$ ) of the scenario.

The total income of all the management zones gives the sum of the specific enterprise and the total of the enterprises gives the sum for the specific scenario. The  $GI$  of a  $SC$  is calculated as:

$$GI_{SC} = GI_{E(I_a+I_b+I_c+I_d+D_a+D_b+D_c+D_d)} \quad (3)$$

where  $E$  is enterprise;  $I_{\#}$  is irrigation enterprise; and  $D_{\#}$  is dry land enterprise.

The cost calculations consist of variable costs and are 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  $TVC$  of a  $SC$  is calculated as:

$$TVC_{SC} = TVC_{E(I_a+I_b+I_c+I_d+D_a+D_b+D_c+D_d)} \quad (4)$$

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 break-even price and yield are simple calculations that can be used to calculate the minimum price and yield that must be achieved for a particular 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 usually expressed as a percentage. The operating profit margin ( $OPM$ ) for an enterprise  $E$  is calculated as:

$$OPM = \left( -\frac{GM_E}{GI_E} \right) \% \quad (5)$$

The SPARÉ model also calculates the total amount of variable inputs used for the different management zones, enterprises, and the whole-farm operation in physical quantities. This information can then be used to determine the change in input use efficiency between PA and CF.

### 3. Results and Discussion

#### 3.1. Identified Management Zones

The PAW (mm) of the fields is shown in Figure 2. The field's clay percentages vary between 5% and 30% and the PAW varies between 35 mm to above 50 mm. The infiltration rate is directly correlated with the clay percentage and it varies between  $25 \text{ mm} \cdot \text{hr}^{-1}$  to as low as  $8 \text{ mm} \cdot \text{hr}^{-1}$ . From the variation in spatial PAW data, five management zones in pie slice-shaped sectors are identified. The management zones (sectors) differ in segments of five from below 35 mm to above 50 mm. The zones are, respectively, 13.9, 47.8, 47.1, 57.3, and 15.6 ha.

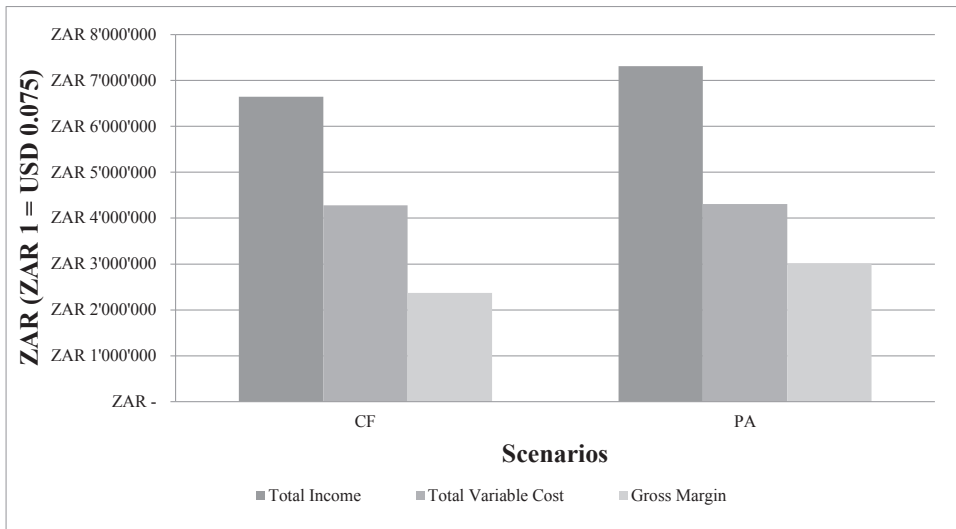


Figure 2. Plant available water map of the study fields.

These identified management zones are used in the decision support model for the PA calculations. The VRI and VRA of fertiliser and amelioration products are then applied in the model in accordance to the crop yield potential of the particular management zone.

### 3.2. Impact of Precision Agriculture

The impact of PA on the sustainability of crop production will first be discussed on the basis of economic sustainability and then on the basis of environmental sustainability. Figure 3 presents a summary of the total income, total variable cost, and the gross margin for CF and PA. It is evident from Figure 3 that although the total variable cost for PA is higher than that for CF, the much higher total income from PA results in a higher gross margin. The total variable cost increase of 0.7% for PA is, thus, offset by the 10% increase in total income and results in an increase of 26.9% in the gross margin.



**Figure 3.** Summary of the total income, total variable cost, and gross margin of conventional farming (CF) and precision agriculture (PA) in South African Rand (ZAR).

The operating profit margin (OPM) is 36% and 41%, respectively, for CF and PA for the whole-farm scenario. Thus, it is 5% higher in the case of PA, making PA more profitable than CF. This also means that PA has a higher return on investment (ROI) than CF for each South African Rand (ZAR) spent.

When comparing the individual enterprises according to CF and PA, it is evident that PA is more profitable than CF. The GM for maize, wheat, and soya beans 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 soya beans it is 20% and 27%, respectively. From these figures it is evident that PA practices are more profitable than CF, with the correct ratio of in-field variation.

While the use of PA does not mean that the total amount of resource use will be less than with CF, by managing the in-field variability the resource use is usually more effective. In order to determine the influence of PA on the environmental sustainability of crop farming it is, thus, necessary to compare the resource use of PA and CF with the yield. The physical total quantities of resources (for example fertiliser, lime, gypsum, fuel, and water) used in tons, kilograms, or litres, are thus divided by the total tonnage of yield for the enterprise to calculate the resource use per ton of output.

The differences in variable input use for the whole-farm scenario between PA and CF are presented in Figure 4. The variable input with the largest saving is the amount of irrigation water applied, which is 24.1% lower in the case of PA. The variable rate irrigation system that is used for PA only applies water where needed and, therefore, the total water use in the case of PA is only 180 mm·ton<sup>-1</sup>, while it is 237 mm·ton<sup>-1</sup> for CF. A total amount of water of 57 mm·ton<sup>-1</sup> of yield is, thus, saved for the specific fields when PA is used instead of CF. The quantities of lime and gypsum, fertiliser and amelioration fertiliser that are used for PA, also differ significantly from CF. In the case of PA, 22.6% less lime and gypsum was applied than with CF, which was a total of 58 kg·ton<sup>-1</sup> of yield. The amelioration fertiliser use was 2 kg·ton<sup>-1</sup> of yield less for PA, while fertiliser use was 24 kg·ton<sup>-1</sup> of yield less.

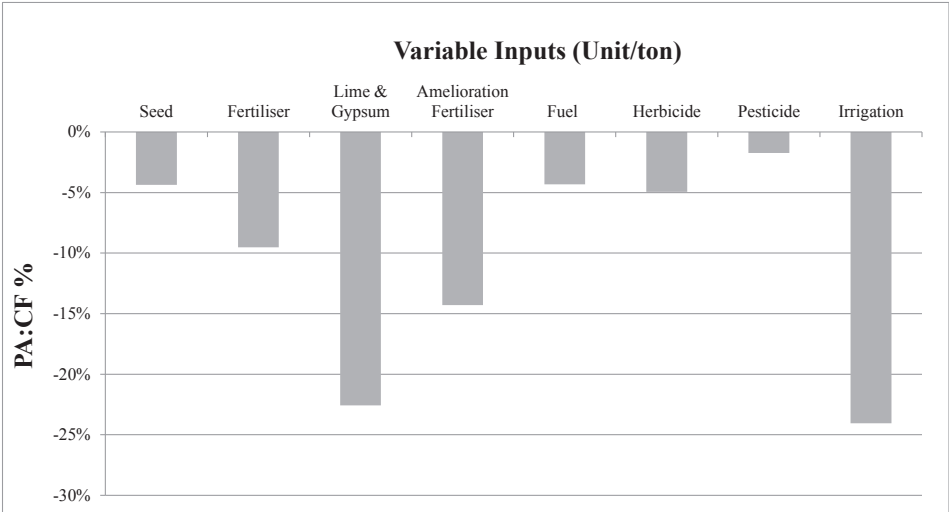


Figure 4. Differences between the variable input use of PA and CF.

## 4. Conclusions

The findings of this article prove that PA may have a positive impact on the sustainability of crop farming for both the economic and environmental dimensions of sustainability. The more sustainable economic dimension was proved by the higher gross margin realised by PA, while the environmental dimension is more sustainable due to the more efficient use of variable inputs, such as water and fertiliser. This finding confirms the findings of Sadler, Evans, Stone, and Camp [14], who found that variable rate irrigation can reduce water usage, and of Lencsés, Takács, and Takács-György [15], who state that PA can reduce the harmful effects of chemical use. The positive impact on the economic dimension will also lead to a more sustainable social dimension of sustainability, as PA produces food more efficiently and, thus, enhances both the availability and affordability of food.

It must, however, be kept in mind that the feasibility of PA practices depends on in-field variation, crop value, economies of scale and the useful life of the equipment. According to Maine “PA has the potential to enhance profitability on South African soils, which are characterised by great variability in depth and fertility within given fields” [16]. VRI is projected to become more essential in the future to protect the scarce water resources in South Africa and the world. Efficiency in agriculture will also become more significant in the future, as more food must be provided to a growing population by using a limited amount of natural resources.

PA is certainly not a new concept, but the adoption of this technology occurs at a relatively slow rate. The higher investment cost in the case of PA (as opposed to CF) and the difficulty to calculate the possible returns beforehand withhold producers from adopting it. This article not only shows what the economic and ecologic advantages of PA can be, but also provides a model that can be applied to calculate these advantages for the producer who considers PA as an alternative to CF.

**Author Contributions:** Frikkie Alberts Maré was responsible for the writing of this article and assisted with the development of the SPARÉ model. Hendrik Petrus Maré identified the management zones with the gamma-ray spectrometer, assisted in the development of the SPARÉ model and collected data for the model from the farmers. Both authors have read and approved the final manuscript.

**Conflicts of Interest:** The authors declare no conflict of interest.

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