REFEREED ARTICLE

DOI: 10.5836/ijam/2017-06-20

The Whole farm financial implications of different tillage systems on different crop rotations in the Swartland area of the Western Cape, South Africa

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ABSTRACT

A Conservation agriculture (CA) is one of the most holistic sustainable agricultural practices yet. It reduces environmental degradation, and concurrently it could enhance farm profitability. A large proportion of the commercial grain producers in the Middle Swartland in the Western Cape Province of South Africa have adopted CA to varying degrees. Adoption of CA in South Africa, has taken place in the absence of any policy support framework directed to CA.

The physical/biological benefits of CA are well known. The financial implications of the various systems within CA, at farm-level varies. Farm systems are complex, consisting of numerous interrelated components, and different farmers' views, preferences and skill sets. A whole-farm budget model is developed within a systems approach to compare various farming systems designed within CA principles. Multidisciplinary group discussions are used to bridge the gap between disciplinary scientific knowledge. To serve as a basis for comparison, the whole-farm model was based on a typical farm within the Middle Swartland relative homogeneous farming area.

The financial evaluation of the various farming systems showed that conventional agricultural practices of monoculture and deep tillage are financially unsustainable. The financial benefits of CA are directly related to improved soil health, lower weed and pest stress and improved yields. The CA farming systems were less susceptible to variations in external factors, highlighting the resilience of the system that incorporates crop rotation and no-till.

KEYWORDS: Conservation agriculture; sustainability; systems thinking; budget modelling; resilience; no-till

1. Introduction

Conservation agriculture (CA) is promoted as an important holistic practice of sustainable agriculture and has experienced high adoption rates across the globe since the mid 1990's (Derpsch and Friedrich, 2010). Conservation agriculture rests on three guiding principles; continuous minimum soil disturbance, permanent organic soil cover, and diversified crop rotations (FAO, 2010). The practice promotes sustainable management of natural resources while increasing agricultural productivity and sustaining the farmer's livelihood, resulting in poverty alleviation and food security (Friedrich and Kienzle, 2007). Every farm has a unique set of ecological characteristics. The guiding principles of CA provide a foundation from which the producer can build a more sustainable farming system according to that unique environment (Knowler and Bradshaw, 2006).

Initial adoption of minimum disturbance and eventually no-till practices were farmer driven and their decisions were based in stewardship of the land. The large scale adoption in the Swartland production area was however based on two key drivers. Firstly, following the deregulation of marketing and the consequential abolishment of the different commodity control boards, farmers were forced to find ways to reduce input costs and remain viable (Vink *et al*, 2011). Secondly, the prevalence of herbicide resistant ryegrass compelled farmers to adopt crop rotations so they could use grass herbicides in the broad leaf cropping phase. No-till planting equipment also enabled farmers to spray one effective herbicide, Trifluralin (Strauss, personal communication, 2014).

Successful conservation agriculture adoption varies throughout South Africa and southern Africa (Thierfelder *et al*., 2012). The Western Cape and Swartland

Original submitted July 2016; revision received November 2016; accepted December 2016.

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(see Appendix 1) is a typical Mediterranean climate region and ideal for winter cereal production. The adoption rate of CA in wheat production systems in this area is relatively high.

Producers appreciate the ecological and economic value of adopting crop rotations. However, the whole-farm financial implications of adopting a CA tillage practice are not well known. Adopting CA tillage requires high capital investment within the system, especially in commercial agriculture, as new machinery is required, equipped with GIS, automated steering, depth control and yield censoring equipment. Decker *et al*. (2009) reported that the no-till machinery prices were nearly double that of conventional machinery. The aim of this paper is to determine the financial implication of the combined effect of tillage and crop rotation systems on farm level over an extended period of time.

2. Materials and Methods

In support of conservation farming, trails are being carried out at Langgewens Experimental farm in Middle Swartland (see Appendix 1). Soils are predominantly Malmesbury and Bokkeveld shales, with a long-term average rainfall of 396.9mm (Wiese, 2013). Two parallel trials are run, one focuses on tillage practices and the other of crop rotation systems. By using the data from both trials, it is possible to gain a more accurate simulation of practical farming systems taking place in Middle Swartland and the associated costs. The four different systems included in the study are:

- Wheat, wheat, wheat, wheat (WWWW)
- Canola, wheat, wheat, wheat (CWWW)
- Wheat, canola, wheat, lupins (WCWL) and,
- Wheat, medic, wheat medic (WMWM).

Yields and production data were recorded on each specific crop (to represent a crop phase in the system). The production activities include; land preparation, planting, fertilization, crop protection and harvesting. The relevant prices of inputs used in each year were also recorded and is based on what producers would pay. An enterprise budget model was built for each crop to evaluate the production cost and gross margins of the different systems.

Conservation agriculture advocates increased yields through rotations in two ways. Firstly, increased yields experienced due to rotations with other crops (Nel *et al*., 2003; Chikowo *et al*., 2004; D'Emden *et al*., 2006; Upendra *et al*., 2009; Thierfelder and Wall, 2010; Nel and Lamprecht, 2011; Kassam *et al*., 2012) such as legumes (medics and lupins), and also non-legume crops like canola. Secondly, by suppressing grass weeds in the broadleaf crops. Rye grass is a weed prevalent in the Middle Swartland area. Both wheat and rye are grass varieties; subsequently there are limited herbicides that can control one without affecting the other. Broadleaf weeds are better controlled during years of cereal production and grass weeds during years of broadleaf crop production. This also effectively reduces the prevalence of herbicide resistant weeds. Wheat monoculture achieved the lowest and most erratic yields in the Langgewens Crop Rotation trials, situated in Middle Swartland area, over the 2007 to 2013 period, competitive rye grass being identified as a causal factor.

Initially producers feared a loss in income with the introduction of broad-leaf cash crops, such as canola, and legumes, such as lupins, into the crop production system. Alternatively, legume pastures associated with sheep production can be implemented. The market for canola, introduced in 1996 in the Western Cape, has grown sufficiently to establish canola as a financially viable cash crop. Improved agronomic practices, suited to the specific environment in Middle Swartland, and better canola seed varieties (resulting from improved selection through canola cultivar trials across multiple testing sites around the production area) increased the attractiveness of canola as a rotation crop and a cash crop.

Reduced cost is generally experienced in crop rotation systems, as opposed to wheat monoculture (Sorrenson *et al*., 1996; Lange, 2005; Llewellyn *et al*., 2009; Crabtree, 2010; Piggen *et al*., 2011). Wheat monoculture is relatively more erratic in terms of non-directly allocated cost, resulting in a lower cumulative gross margin as shown in Figure 1.

Systems Analysis and Whole Farm Budgeting

The challenges that producers face require short-term tactics as well as medium to long-term strategies. The study of these challenges is complicated by the gaps in expert knowledge, typically created by specialization and gaps between academic and practical knowledge. Multi-disciplinary discussions provide a platform to bridge this gap. This requires the involvement of various participants including; researchers, producers, agribusinesses, advocacy groups and private consultants (Power *et al*., 2011). This allows research to collectively identify actionable solutions that incorporate the dynamics of the whole farm, generate a realistic whole farm model and simulate more real world scenarios.

With computer technology, budgets can be adapted to accommodate more multi-faceted systems (Nuthall, 2011). Using spreadsheet programs, whole farm budget models can handle complex calculations and relationships, yet are adaptable and user-friendly. This classifies the budgeting technique as simulation based on accounting principles. Multi-period, whole-farm budget models can calculate the Internal Rate of Return on capital investment (IRR) and Net Present Value (NPV) (Hoffmann, 2010).

For the purposes of this research, a typical farm, that is representative of the Middle Swartland grain farm, model was developed to provide a basis of comparison for the expected impacts of specific systems and possible external impacts. A typical farm is defined as a farm representing what a group of farmers do within an essentially homogeneous area (Feuz and Skold, 1992). This was applied to assess the crop trial results on the whole farm level. The whole-farm structure was validated by expert stakeholders such as scientists, producers, and economists during a multidisciplinary workgroup discussion. The farm was initially defined with the inputs of local extension officers. The budget model, firstly, determines the current financial position of the typical farm. Secondly, it is used to compare the financial implication of alternative production systems and thirdly, evaluate the profitability impact of exogenous variables in the form of scenarios. Standard accounting principle was followed within the standard structure of whole farm budgets.

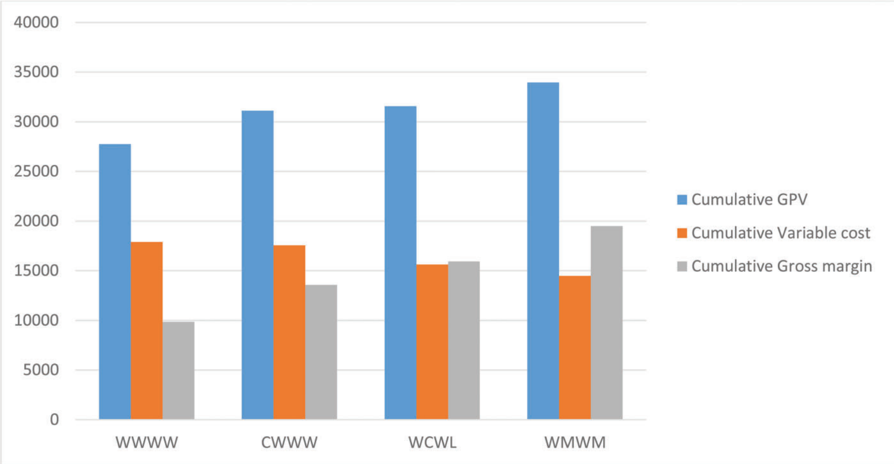

Figure 1: Cumulative gross production value (At the time of writing (mid-June 2016), R1.00 was approximately equivalent to $US0.07, £0.05, €0.06.), variable cost, and gross margin per system from the Langgewens Trials, for period 2002-2011

The expert group suggested Langgewens research farm as the basis for defining a relatively homogenous area. Characteristics defining a homogeneous area include; climate, terrain and soil type, and farming practices. The climatic conditions in this area are characterized by rainfall between 250-450mm in the winter between April and mid-October, with typically dry hot summers. The soils are predominantly Malmesbury shale, consisting of shallow sandy-loam soils. The area is a traditionally wheat producing area with rotations of canola and lupins. Medic pastures for sheep are also rotated with wheat.

A representative farm serves as basis to which farmers in a homogeneous area can relate. This is done by mimicking a farm on the most common physical farm parameters found in the area. Within the whole-farm model, the typical farm size determines; area cultivated, land utilization, mechanization, labour requirements, and investment in fixed improvements. The expert group agreed on a typical farm for the Middle Swartland area, as shown in Table 1.

The expert group considered and agreed to the structure and values of the typical farm. This includes land and fixed improvements, movables, and sheep. The investment in sheep is determined by the land under pasture and stocking rate. The composition of the herd is derived from assumptions on ram to ewe ratio and the ewe replacement policy. The output values for the sheep enterprise were obtained from local agribusiness and the Langgewens trial data. The value of the herd, including rams, ewes, replacement ewes and lambs were obtained from local agribusiness and experts in sheep husbandry.

The crop rotation systems that were included in the group discussion were accepted as the three most commonly practiced crop rotation systems used in the Middle Swartland and compared to wheat monoculture. Wheat still forms the basis of the rotations used in the Middle Swartland and all the systems maintain at least half the area under wheat cultivation. Tillage can influence both yield and variable cost to the enterprise. The traditional form of tillage known as conventional tillage (CT) is compared to the increasingly popular No-till (NT) practice advocated by CA.

Crop yields vary due to seasonal variations. To incorporate this risk factor into the model, the prevalence of good, average and poor years were identified. Rainfall scenarios for the Middle Swartland were obtained from local weather stations and personal communication with producers and local agribusiness extension officers. It was found that despite a number of good seasons from 2011, the prevalence of good, average, and poor years would likely still follow the same pattern as identified in a previous study (Hoffmann, 2010). Good, average, and poor years are caused by dispersion of rainfall throughout the season and influence the profitability of the whole-farm over an extended period of time. Each of the three seasonal variations can be defined as follows:

Table 1: Physical description of typical Middle Swartland farm

Homogeneous Area	Middle Swartland
Typical farm size (ha)	800
Land Price R/ha	30,000
% Arable Land	95%
Ha Arable Land	760

- A good year: represent the ideal rainfall conditions to provide the crop with sufficient water throughout the growing season.
- An average: adequate total annual rainfall, however the dispersion would be disruptive to plant growth, for example, there may be insufficient rainfall to establish the crop or at seed filling time, resulting in reduced yields.
- A poor year: both erratic rainfall dispersion and a low annual total rainfall, resulting in low yields. This includes the prevalence of droughts.

Yield data, presented during the expert group meeting for discussion, were derived from production guidelines combined with data from the Langgewens crop rotation trials (Strauss, 2013 and Labuschagne, 2013). The expert group confirmed the expected yields in Middle Swartland for good, average, and poor years as well as the expected frequency within a ten-year period. The key yield assumptions provided by the expert group are highlighted in Appendix 2.

Wheat yield for both no-till (NT) and conventional tillage (CT) in a poor year is 1600kg/ha as shown in Appendix 2. The benefit of moisture retention in NT is traded off with the benefit of mechanical weed control in CT. Soil moisture retention is mitigated by rainfall dispersion in average and good years; therefore wheat yields under CT outstrip yields under NT.

Under a rotation system with legumes, wheat yields are higher than in a monoculture system because of nitrogen fixation in the rotation, and more effective weed control. Improved weed control trough rotation, results in benefits of no-till being realized such as soil moisture retention and improved soil structure and fertility. The result is higher yields under NT than under CT. The relative benefit of soil moisture retention declines as rainfall patterns improve in average and good years.

The benefits of the crop rotation system also apply to the WMWM system, shown in Appendix 2. The additional increase in wheat yield compared to the LWCW system is attributed to the enhanced nitrogen fixing properties of medics compared to lupin and canola, a non-legume crop. Medics have shallower root systems and re-establish themselves in the following year, thereby reducing traffic on the field and further exaggerating the effect of reduced tillage on soil structure and fertility.

Cropping canola in the rotation system shows similar increased yields in the following wheat crop as lupins and medics do, even though canola is not a legume. The improvement in the yield of wheat following a canola crop might be attributed to better grass weed control which lowers seed bank numbers that could compete with the following wheat, the crops taproot system helps to improve water infiltration and possible phosphorus mobilisation. Canola offers a financially viable alternative cash-crop to rotate with wheat. Appendix 2, Table 4 shows the consecutive wheat yields following canola. Increases in wheat yield directly following canola crops follow the same trend as seen in Appendix 2, Table 2. The second consecutive wheat crop in the rotation records an increase in yield of 14 percent on a typical wheat monoculture crop. The third consecutive wheat crop should see an 8 percent increase on a typical wheat monoculture crop (Hoffmann, 2011 and Strauss, 2014). Thereafter, wheat yields begin to decline.

Appendix 2, Table 5 shows the yields of canola and lupin validated during the group discussions. The expert group agreed that these crops would follow similar trends under the different tillage practices as the wheat crop with higher yields under no-till as compared to conventional tillage.

Sheep were brought into the crop production systems of the Middle Swartland area for diversification purposes. Sheep were included at standard practices and composition as determined by the group. Bias was more towards performance of the crops.

Analysis of financial vulnerability through scenarios

A scenario is a hypothetical description of a possible future (Therond *et al.*, 2009), or the variation in the assumptions used to create models (Peterson *et al.* 2003). Scenarios are widely used in research to assess the impact of 'what if questions'. For instance; 'what will the impact of whole-farm profitability be if the wheat price decreased by 10 percent?' Under normal circumstances, in the event of declining commodity prices, producers are likely to substitute one crop for another. For the purpose of this research a *ceteris paribus* principle is factored into the scenarios. *Ceteris paribus* in economic terms refers to the effect of one economic variable on another, while holding all other variables constant.

The model can depict the impact of changes in various assumptions on whole-farm profitability. The scenarios included are; increased input prices, declining wheat price, and devaluation in the Rand to the US dollar raising the price of machinery and fuel.

Model Variables

The data consist of various attributes of each item used as an input in the production process. These attributes include; brand name, unit of sale, recommended application rates per hectare for the product, and the unit price. Product prices were derived of a three-year average of input prices from Langgewens research farm (2011-2013). If product prices were not available, a three-year average was taken from industry.

The output price used in the model was derived from a three-year average price of the specific commodity. The price of wheat was derived from the three quality grades, B1, B2, and B3. A typical blend of quality per ton was obtained from local agribusiness and study group data. The running costs and purchase price of machinery was incorporated using the 'Guide to machinery costs' recently developed and released by local agribusinesses in the Western Cape (Guide to machinery costs, 2014). The expert group agreed on the mechanisation requirements.

The main difference between the farm inventories, for the various farming systems in the model, occurs with the wheat medic rotational system. In the wheat/medic system 50 percent of the arable land is under wheat and the remaining 50 percent under medic pastures. The machinery requirements differ as medics re-establish themselves in the year following wheat. The result is a lower kilowatt requirement and smaller implements can be used. The input costs contributing to total variable costs remained the same irrespective of the seasonal performance. This excludes silo costs, which are determined by the yield.

3. Results

The first set of trial data focus specifically on soil health and adopted a blanket effect of all production activities above the surface including machinery movement, soil disturbance, cover crops and grazing. As a result, the crop yields are very erratic and in some instances, where weeds have out-competed the wheat, yields were not recorded. This makes it very difficult to directly analyse the financial outcomes of the cropping systems as the trials were not designed or intended for economic analysis. What does stand out from the financial analysis is the evidence of reduced input costs and increased yields under crop rotations, refer to Figure 2 and Table 2. This is in line with the principles of CA.

Figure 2 shows the average non-directly allocatable costs for the three tillage practices; no-till (NT), minimum-till (MT), and conventional-till (CT), under the three rotation systems, based on the Langgewens crop trials. There are two sets of data for the rotation of wheat, canola, wheat, lupin (WCWL). The two graphs depict wheat following canola (LWCW), and wheat following lupin (CWLW). Below the non-directly allocatable cost graph, is the corresponding average gross margin for the same crop within the crop rotation and tillage practice. It is clear evidence of a reduction in non-directly allocatable costs. This is because CA tillage practices constitute lower mechanical costs due to less movement over the field.

The second set of Langgewens trial data comprises crop rotation trials that began in 1996 and are still active. This research highlighted four of the rotations being trialled, namely wheat monoculture (WWWW), wheat, lupin, wheat, canola rotation (WCWL), wheat, medic rotation (WMWM), and canola, wheat, wheat, wheat rotation (CWWW). Wheat monoculture achieved consistently lower yields than wheat in rotation. In 2003 the Western Cape experienced a severe drought resulting in wheat planted in the 4 cash crops systems not being harvested. Since the system is based on a cash crop sequence and does not have an animal factor the resulting residue was not grazed. The only harvestable wheat crop was that of wheat in rotation with medics. The yield and input cost data was captured in enterprise budget models designed to relate the physical input/output quantities into gross margins. Figure 3 shows the gross margins per hectare achieved under each crop rotation system. The consistent yields and low input costs of wheat in rotation with medics are depicted in a less erratic curve.

Gross margin analysis

The budget model calculates a gross margin for each crop under both no-till and conventional-till practices, as well as a whole-farm gross margin for both practices, across all the crop rotation systems. The gross margin is calculated by subtracting the variable costs of production from the gross production value.

Table 2 shows the whole-farm gross margin and gross margin per hectare for the different crop rotation systems and under differing tillage practices. The data used for calculating the gross margins presented in Table 2 was obtained from the Langgewens crop rotation and Langgewens tillage trials. Physical inputs and yields were calculated from 2002 - 2012 trail data.

Whole-farm financial performance

The budget model measures the profitability of the typical farm over a 20 year period. The financial performance is measured in the internal rate of return on capital investment (IRR) and net present value (NPV) of the future expected cash flow. The IRR and the NPV are calculated

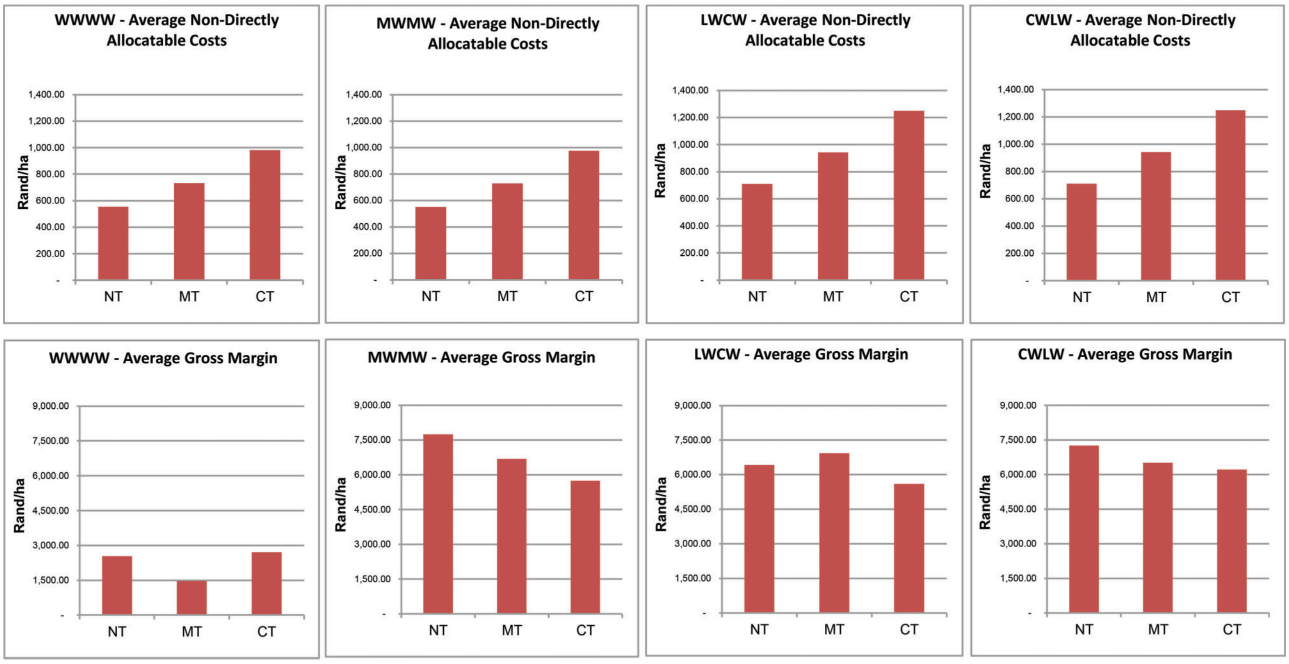

Figure 2: Trends in the non-directly allocatable costs and the gross margins of crop systems

Table 2: Total gross margin for good, average, and poor seasons for each crop rotation system

Crop	Tillage	Gross margin for whole-farm and gross margin per hectare					
Rotation	Practice	Good year		Average year		Poor year	
System		R/farm	R/ha	R/farm	R/ha	R/farm	R/ha
WWWW	NT	4 089 682	5 381	2 611 622	3 436	693 556	912
	CT	3 857 682	5 075	2 165 879	2 849	37 041	48
WCWL	NT	4 705 670	6 191	3 119 248	4 104	1 249 319	1 643
	CT	3 994 159	5 255	2 193 995	2 886	245 357	322
WMWM	NT	4 386 982	5 772	3 537 951	4 655	2 370 532	3 119
	CT	3 803 974	5 005	2 742 684	3 608	1 681 395	2 212
CWWW	NT	5 122 049	6 739	3 444 471	4 532	1 330 071	1 750
	CT	4 269 781	5 618	2 272 330	2 989	248 742	327

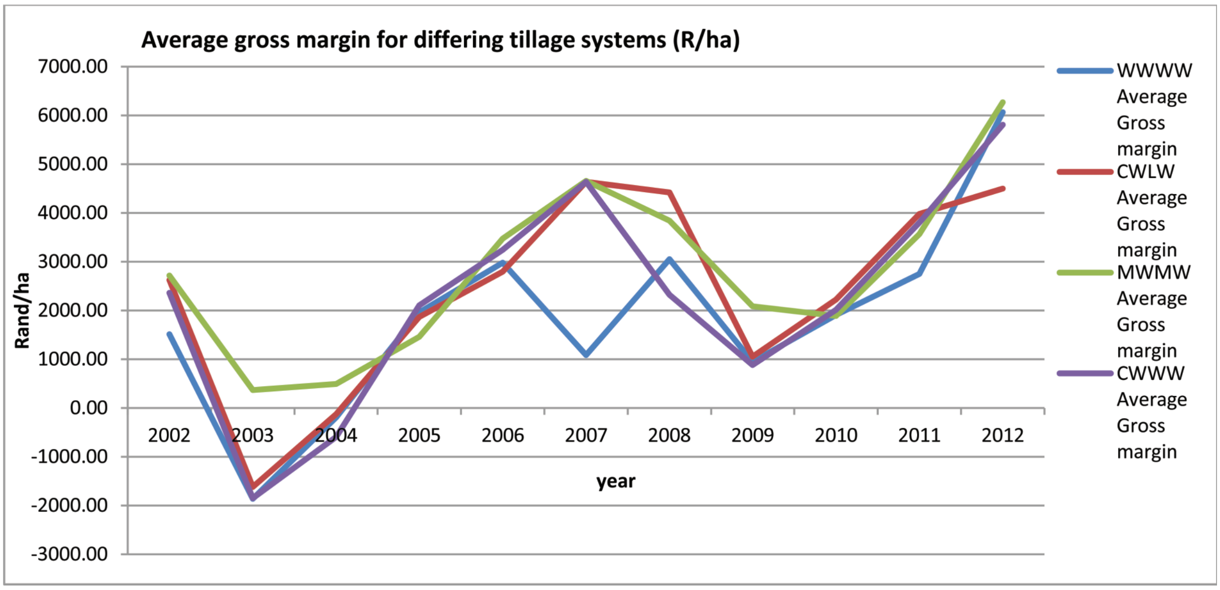

Figure 3: Average gross margins (R/ha) of different crop rotation systems from 2002-2012

for each farming system, which includes the rotational system and tillage practice. The IRR and NPV are calculated in the whole-farm multi-period budget sheet.

Table 3 shows the NPV and the IRR for each of the crop rotation systems under the different tillage practices over a 20 year period. The average nominal interest rate was 9.0 percent, the inflation rate 6.1 percent, and the real interest rate 2.73 percent (Statistics South Africa, 2014, and South African Reserve Bank, 2014).

When the IRR falls below the real interest rate (2.73%), the NPV moves into a negative value, as the investment over a 20-year period will yield a negative return. Table 3 shows that all of the farming systems practicing conventional tillage return an IRR below the real interest rate and a resultant negative NPV. These options are consequently unattractive to investment. In the case of wheat monoculture (WWWW), the farming system under both no-till and conventional tillage practices, renders a negative NPV and an IRR below the real interest rate. Wheat monoculture is therefore unattractive to investment irrespective of tillage practice. Wheat monoculture production under conventional strategies degrades soil over time due to excessive tillage, while under no-till production the weed management becomes a problem due to the development of herbicide resistance over time.

The WCWL system's profitability suffers as lupins do not generate a viable market price and yields are erratic. Despite a positive effect on wheat yields following lupin, the poor gross margin of the lupin enterprise decreases the whole-farm profitability under this crop rotation system. The WCWL system was included in this study because it is part of the Langgewens trials. Other legumes such as chickpeas and fava beans could have been used as an alternative, but was not available to use at the initiation of the trials and the lupins was thus kept to ensure the integrity of the long term trial.

Wheat in a medic (sheep) rotation (WMWM) is the only system that offers a higher IRR under conventional tillage. The reason is that in the agronomical research there was no conclusive evidence that a pasture system under no-till would increase the output of the sheep enterprise. There is little evidence to support a higher stocking

Table 3: The net present value (NPV) and internal rate of return on capital investment (IRR) for each typical crop rotation system

Crop Rotation System	Tillage Practice	Internal Rate of Return (IRR)	Net Present Value (NPV)
WWWW	NT	2.24%	R -2 028 333
	CT	1.29%	R -5 812 838
WCWL	NT	4.06%	R 5 425 665
	CT	1.39%	R -5 449 243
WMWM	NT	4.69%	R 7 981 843
	CT	2.56%	R -712 778
CWWW	NT	5.39%	R 10 684 593
	CT	1.93%	R -3 241 267

rate of sheep on medic pastures following wheat. Pastures, in a good year, would generate larger quantities of grazing for sheep, it is difficult for the producer to predict the weather in time and buy or sell sheep accordingly. Additional supplementary feeds can be bought in poor years; however, there is no research on this to support assumptions on feeding levels. For this reason, the output generated from sheep on medic pastures is kept constant irrespective of tillage practice or seasonal variations of good, average, and poor years.

Furthermore, under the mixed crop/sheep rotation system, the producer is unable to take full advantage of a really good year because half of the area available for crop production is under pastures. Therefore, although the WMWM rotation may enjoy the buffer effect in a poor year, the limitations in a good year result in a lower IRR potential for the whole-farm system.

The CWWW rotation system records the highest IRR and NPV of the four rotation systems. The reasons for this are; firstly, the producer is able to take full advantage of a good year because all the rotation crops in the system generate a high gross margin. Canola is a profitable cash crop and the benefits of the crop rotation generate high yields for wheat following canola when compared to wheat monoculture. As expressed in Appendix 2, Table 5, the benefits of wheat following canola are not limited to the first year but also benefit subsequent years of wheat cultivation, although at a diminished rate. Secondly, the benefits increased yields under no-till further enhance the profitability of the system.

Further to this, the reason the CWWW system records a negative and subsequently a relatively high gap in profitability between no-till and conventional-till is because the system lacks a buffer effect in the poor years, enjoyed by the WMWM system.

Increasing input cost

The first scenario assessed the profitability impact of an increase in input costs. This was aimed at determining the impact of input price inflation on the typical farm for each of the different systems. Fertiliser, chemicals, and fuel, contribute the largest components of the variable costs. A simulated increase in input costs of 10 percent, 20 percent, and 30 percent was used to evaluate the impact on the IRR. The results of the simulation are shown in Table 4. The current situation is depicted in the left four columns under 'Whole-farm model'. The columns to the right under the title 'Rising input cost scenario' show the IRR in the event of a percentage change in input prices. The relative change in the IRR is the percentage change between the current IRR and the new IRR.

Firstly the significance of tillage is highlighted. Table 4 shows that, compared to a conventional tillage system, the no-till system is less susceptible to rising input prices. Under conventional tillage an increase in input prices results in double the relative change in the IRR (74 percent) as compared to the relative change in the IRR under no-till (33 percent). Conventional tillage reduces organic matter and carbon levels in the soil making it more input intensive. An estimated 50 percent more nitrogen is required to produce the crop than under no-till practices.

A conservation agriculture system, of combined no-till and crop rotation, shows less than half the relative change in the IRR compared to a conventional system as affected by rising input prices. Table 4 shows that the worst performing crop rotation system is wheat, canola, wheat, lupin (WCWL) under no-till in terms of relative change in the IRR. A 10 percent rise in input prices to the system shows a 15 percent relative change in the IRR. A wheat monoculture system (WWWW) under conventional tillage shows a relative change in the IRR of 74 percent. This highlights the buffering effect of increased yields, generated by rotations in the cropping system, to the impact of rising input prices.

Lower wheat price

Table 5 shows that a 10 percent decline in the wheat price would cause an expected 35 percent relative change in the IRR, for the most profitable farming system (CWWW). This is more than double the relative change in IRR for the same system (CWWW, 13 percent) in the event of a 10 percent rise in input costs. This system (CWWW) is expected to experience a relative change in the IRR of 35 percent, a decrease in the IRR to 3.53 percent in the event of a 10 percent decline in the wheat price. It is expected that a 30 percent rise in input prices could have a similar effect to the systems IRR, decreasing it to 3.37 percent.

In the WMWM system, only 50 percent of the area is under wheat. More importantly, the wheat yields are more stable and higher than that of the wheat in the monoculture system. The impact of declining wheat prices is consequently expected to be less in contrast to the wheat dependent systems. Table 5 shows that the expected effect of a 10 percent decline in wheat price, results in a lower relative change in the IRR for the WMWM system as opposed to the CWWW system. The actual IRR remains lower at 3.22 percent as opposed to 3.53 percent respectively. After a 30 percent decline in wheat price, the WMWM system records an actual IRR of 0.37 percent while the CWWW system falls into a negative IRR at -0.07 percent. This shows that the WMWM system is less susceptible to declining wheat prices.

Machinery cost as impacted by exchange rate

The group discussions expressed concern over the continued devaluation of the Rand to the US dollar and the potential increase in cost of replacing machinery. The price of planting equipment required for CA is high, therefore the aspect of path dependence and subsequent narrowing of options due to the high investment requirements in creating production capacity in winter cereal systems, can be highlighted. Adopting CA is not a straightforward decision because the financial implications of potentially reduced income during the initial phases of adoption are compounded by the large capital investment

Table 4: Relative percentage change in IRR as a result of an increase in input costs.

Whole-farm model				Rising input cost scenario					
				10% ↑		20% ↑		30% ↑	
Crop Rotation System	Tillage Practice	Internal Rate of Return (IRR)	Net Present Value (NPV)	Internal Rate of Return (IRR)	Relative change in IRR	Internal Rate of Return (IRR)	Relative change in IRR	Internal Rate of Return (IRR)	Relative change in IRR
WWWW	NT	2.24%	R -2 028 333	1.50%	33%	0.76%	66%	0.03%	99%
	CT	1.29%	R -5 812 838	0.33%	74%	-0.62%	148%	-1.55%	220%
WCWL	NT	4.06%	R 5 425 665	3.45%	15%	2.84%	30%	2.23%	45%
	CT	1.39%	R -5 449 243	0.64%	54%	-0.11%	108%	-0.85%	161%
WMWM	NT	4.69%	R 7 981 843	4.14%	12%	3.60%	23%	3.05%	35%
	CT	2.56%	R -712 778	1.95%	24%	1.26%	51%	0.58%	77%
CWWW	NT	5.39%	R 10 684 593	4.71%	13%	4.04%	25%	3.37%	37%
	CT	1.93%	R -3 241 267	1.06%	45%	0.21%	89%	-0.64%	133%

Table 5: Relative percentage change in the IRR as a result of a decline in the wheat price

Whole-farm model				Wheat price decline scenario					
Wheat R2 792.87/ton (3 year average, 2011-2013)				10% ↓	R 2 514	20% ↓	R 2 234	30% ↓	R 1 955
Crop Rotation System	Tillage Practice	Internal Rate of Return (IRR)	Net Present Value (NPV)	Internal Rate of Return (IRR)	Relative change in IRR	Internal Rate of Return (IRR)	Relative change in IRR	Internal Rate of Return (IRR)	Relative change in IRR
WWWW	NT	2.24%	R -2 028 3337	0.22%	90%	-1.76%	179%	-3.70%	265%
	CT	1.29%	R -5 812 838	-0.83%	164%	-2.90%	325%	-4.93%	482%
WCWL	NT	4.06%	R 5 425 665	2.69%	34%	1.33%	67%	0.00%	100%
	CT	1.39%	R -5 449 243	0.13%	91%	-1.12%	180%	-2.34%	268%
WMWM	NT	4.69%	R 7 981 843	3.22%	31%	1.78%	62%	0.37%	92%
	CT	2.56%	R -712 778	1.25%	51%	-0.12%	105%	-1.46%	157%
CWWW	NT	5.39%	R 10 684 593	3.53%	35%	1.71%	68%	-0.07%	101%
	CT	1.93%	R -3 241 267	0.24%	88%	-1.41%	173%	-3.03%	257%

Table 6: Relative percentage change in IRR as a result of an increase in base costs of machinery and fuel

Whole-farm model				Rising fuel and machinery cost scenario					
				10% ↑		20% ↑		30% ↑	
Crop Rotation System	Tillage Practice	Internal Rate of Return (IRR)	Net Present Value (NPV)	Internal Rate of Return (IRR)	Relative change in IRR	Internal Rate of Return (IRR)	Relative change in IRR	Internal Rate of Return (IRR)	Relative change in IRR
WWWW	NT	2.24%	R -2 028 333	1.84%	18%	1.45%	35%	1.08%	52%
	CT	1.29%	R -5 812 838	0.89%	31%	0.50%	61%	0.12%	91%
WCWL	NT	4.06%	R 5 425 665	3.64%	10%	3.23%	21%	2.83%	30%
	CT	1.39%	R -5 449 243	0.99%	29%	0.61%	56%	0.24%	83%
WMWM	NT	4.69%	R 7 981 843	4.38%	7%	4.07%	13%	3.77%	20%
	CT	2.56%	R -712 778	2.33%	9%	2.02%	21%	1.72%	33%
CWWW	NT	5.39%	R 10 684 593	4.93%	9%	4.49%	17%	4.07%	24%
	CT	1.93%	R -3 241 267	1.51%	22%	1.11%	42%	0.72%	63%

required to purchase the necessary machinery. This can have a significant impact on the cash flow of the business and profitability. The rising costs of machinery may deter potential CA adoptees. They would instead continue producing conventionally. This research shows that conventional practices are not viable in the long term, and that CA poses the best option for reducing costs to increase profit.

One of the greatest savings from adopting CA has been the reduction in; kW power requirement, repairs and maintenance on machinery, and fuel (Bignell, personal communication, 2014). Conservation agriculture reduces soil tillage. Therefore, less power is required to establish a crop.

Increases in the price of machinery and fuel of 10 percent, 20 percent, and 30 percent was simulated to evaluate the impact on the profitability. Table 6 shows the actual and relative changes in the IRR in the event of rising fuel and machinery costs. The conventional system shows significantly higher relative expected changes to the IRR when compared to the systems under conservation agriculture (WCWL, WMWM, CWWW).

The WMWM system operates with a lower total inventory value, as only 50 percent of the area is under cash crops, therefore requiring fewer and smaller capacity machinery. The WMWM system subsequently experiences the lowest relative change in the IRR.

4. Conclusions

The Middle Swartland is traditionally a well-known wheat production area in South Africa, but is challenged by relatively erratic rainfall patterns and shallow soils. To support sustainable farming practices various crop rotation and tillage practices are being researched at Langgewens experimental farm in the Middle Swartland. A multi-period budget model, supported by multidisciplinary group discussions, was developed to firstly, establish the current profitability of the typical farm, and secondly to evaluate the impacts of variations in the external environment. The dynamics of the model allow it to incorporate the complication of interrelationships between variables within the whole-farm system. This model was used to determine the current profitability of the typical farm under various crop rotation systems and tillage practices to establish the expected profitability of each farming system.

Three scenarios were selected from issues raised during the group discussions and included; rising input costs, declining wheat price, and rising machinery and fuel costs. A lesser impact is expected, based on wheat price, on the profitability of the farming systems with wheat in rotation with canola, lupins, and medics/sheep when compared to the monoculture system. The rotation systems are diversified into various crops, the impact of a decline in a single commodity price would not be as significant as for the monoculture system. The increased yields generated from the crop rotations and no-till also offer a buffering effect in the event of declining wheat prices.

The effect of an increase in input prices has a greater impact on conventional tillage systems that are input intensive. The increased yields in the rotation systems and under no-till serve as a buffer against the effect of inflation on input prices. In the case of increased machinery and fuel costs, the WMWM system was least affected. Only 50 percent of the area cropped was under cash crops, which means less mechanical and fuel requirements.

All the crop rotation systems performed better in terms of profitability than the wheat monoculture system. This is due to the combine effects of increased yields, lower costs and diversification of crop rotations. All the systems under no-till are expected to be more profitable than the systems under conventional. This is caused by the benefits from reduced input costs and mechanical investment. Overall the CA system with crop rotation combined with no-till has the highest expected profitability over the 20-year period. It is still uncertain what the implications of different sheep production systems might contribute to profitability as well as the impact of cover crops. Those two factors should be included in future research.

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Acknowledgements

The authors are grateful to the Western Cape Agricultural Trust for the financial assistance that made this project possible.

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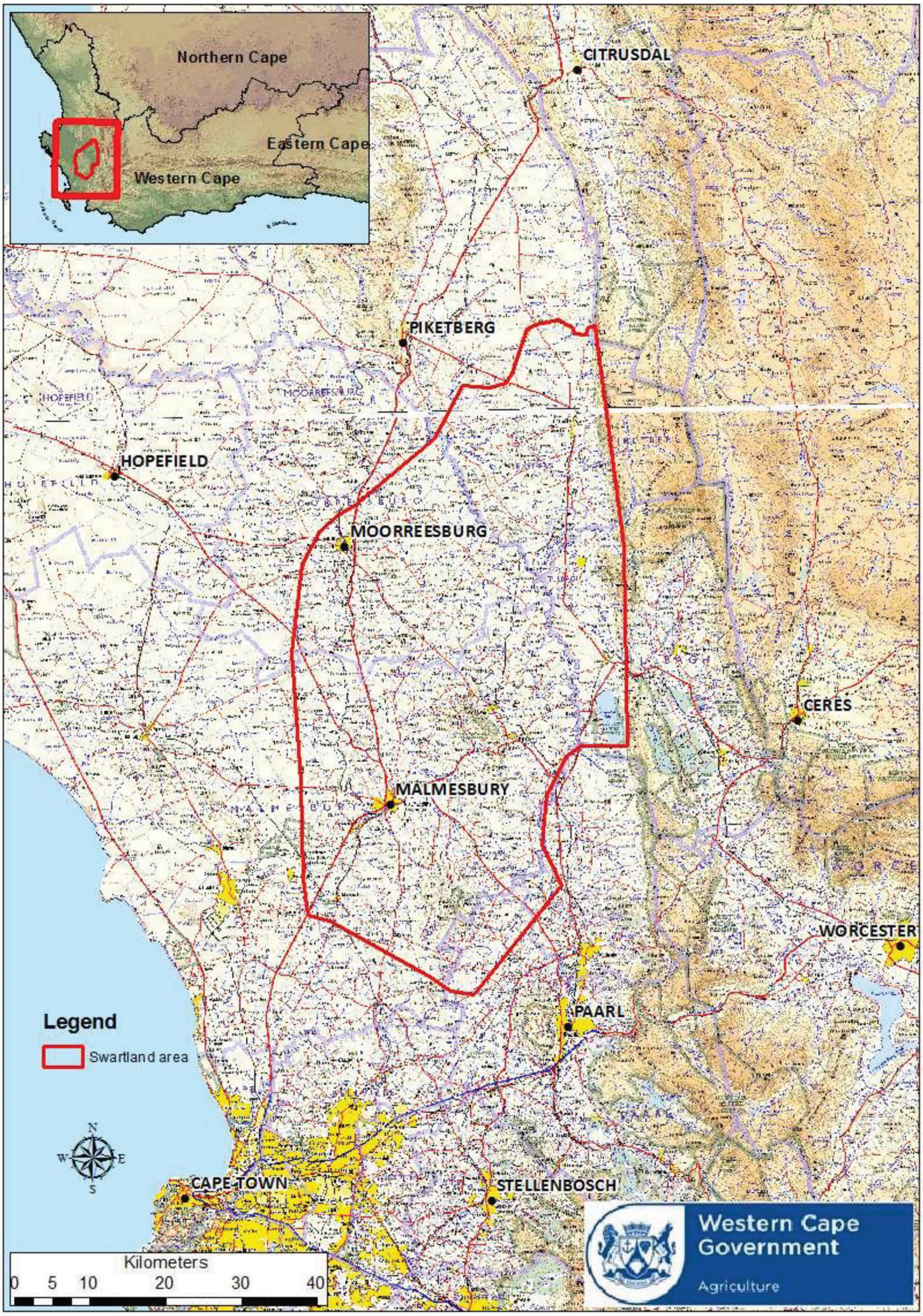
Appendix 1

The Western Cape and Swartland



Appendix 2

Table 1: Wheat monoculture yield values and frequency validated by the expert group discussions

WHEAT YIELDS		EXPERT GROUP VALIDATED YIELD VALUES/HA	
CROP SYSTEM		**WHEAT MONOCULTURE (WWWW)**	
TILLAGE PRACTICE	Frequency	No-till	Conventional-till
POOR YEAR	2	1,600	1,600
AVERAGE YEAR	7	2,500	2,600
GOOD YEAR	1	3,200	3,400

Table 2: Wheat/Canola/Lupin rotation system wheat yield values and frequency validated by the expert group discussions

WHEAT YIELDS		EXPERT GROUP VALIDATED WHEAT YIELD VALUES KG/HA FOR SYSTEM LUPIN, WHEAT, CANOLA, WHEAT	
CROP SYSTEM		**(LWCW)**	
TILLAGE PRACTICE	Frequency	No-till	Conventional-till
POOR YEAR	2	2,350	2,100
AVERAGE YEAR	7	3,400	3,100
GOOD YEAR	1	4,100	4,000

Table 3: Wheat/Medic rotation system wheat yield values and frequency validated by the expert group discussions

WHEAT YIELDS		EXPERT GROUP VALIDATED WHEAT YIELD VALUES KG/HA FOR SYSTEM WHEAT, MEDIC, WHEAT, MEDIC	
CROP SYSTEM		**(WMWM)**	
TILLAGE PRACTICE	Frequency	No-till	Conventional-till
POOR YEAR	2	2,500	2,200
AVERAGE YEAR	7	3,600	3,200
GOOD YEAR	1	4,400	4,200

Table 4: Wheat/Canola rotation system wheat yield values and frequency validated by the expert group discussions

WHEAT YIELDS		EXPERT GROUP VALIDATED WHEAT YIELD VALUES KG/HA FOR SYSTEM WHEAT/CANOL ROTATION (WCWW)					
CROP SYSTEM		**CWWW 8%**		**WCWW 14%**		**WWCW**	
TILLAGE PRACTICE	**Frequency**	**No-till**	**Conventional-till**	**No-till**	**Conventional-till**	**No-till**	**Conventional-till**
POOR YEAR	2	1728	1600	1824	1624	2350	2100
AVERAGE YEAR	7	2700	2400	2850	2550	3400	3100
GOOD YEAR	1	3456	3356	3648	3548	4100	4000

Table 5: Canola and lupin yield values and frequency validated by the expert group discussions

CANOLA YIELDS		EXPERT GROUP VALIDATED CANOLA YIELD VALUES KG/HA FOR SYSTEM WHEAT, LUPIN, WHEAT, CANOLA	
CROP SYSTEM		**(WLWC)**	
TILLAGE PRACTICE	**FREQUENCY**	**No-till**	**Conventional-till**
POOR YEAR	2	800	700
AVERAGE YEAR	6	1,400	1,300
GOOD YEAR	2	2,000	1,900

LUPIN YIELDS		EXPERT GROUP VALIDATED LUPIN YIELD VALUES KG/HA FOR SYSTEM WHEAT, CANOLA, WHEAT LUPIN	
CROP SYSTEM		**(WCWL)**	
TILLAGE PRACTICE	**FREQUENCY**	**No-till**	**Conventional-till**
POOR YEAR	2	700	600
AVERAGE YEAR	6	1,300	1,200
GOOD YEAR	2	2,000	1,900