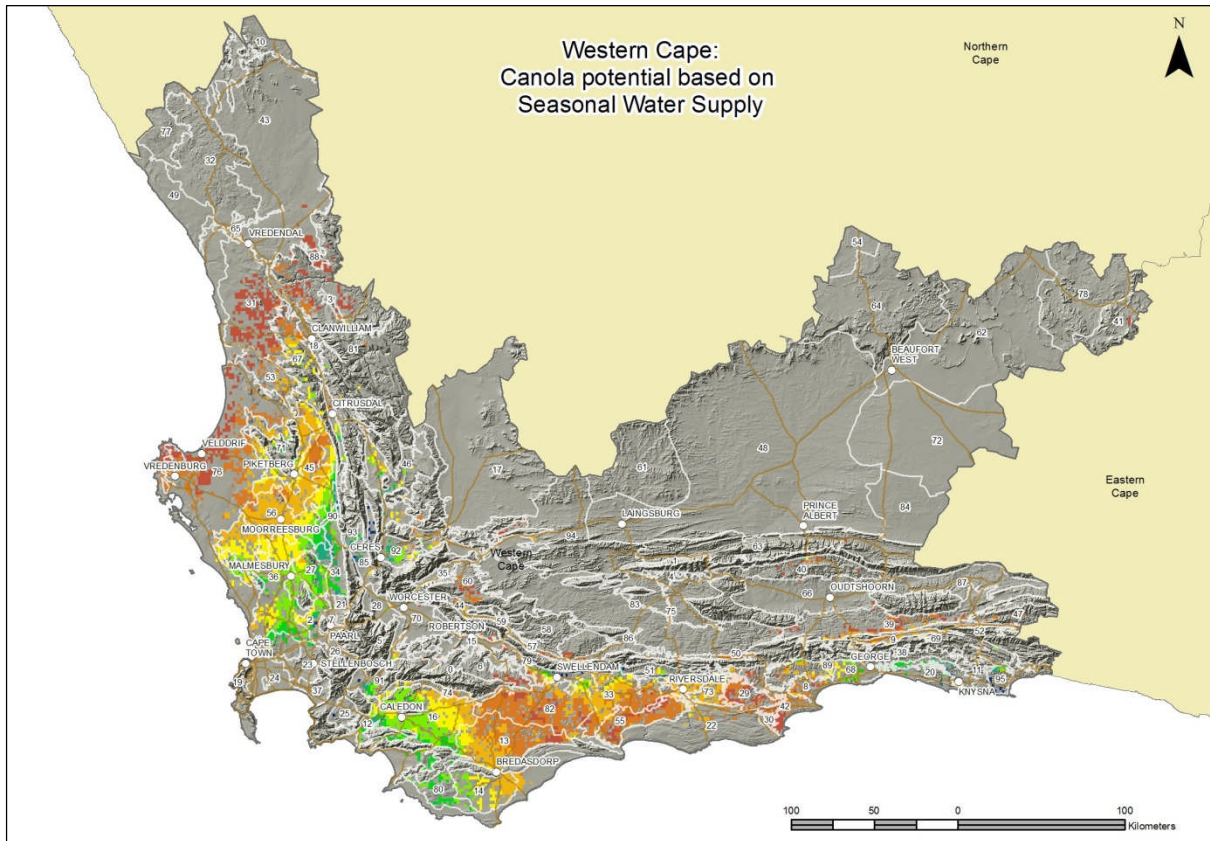


Determining the area of arable land suited to canola production in the Western Cape

Volume 1: TEXT



Dr MB Hardy and Mr MG Wallace

FINAL REPORT

Determining the area of arable land suited to canola production in the Western Cape

VOLUME 1 - TEXT

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Volume 1: TEXT

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Volume 2: Figures and Tables

Executive summary

Final Report: Determining the area of arable land suited to canola production in the Western Cape

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Introduction

The objective of this study was to determine the total area of rainfed arable land suited to canola production, and to develop tables and maps showing canola production regions in the Western Cape Province. Data sets from the DAWC and PICES provided baseline data on the areas of land allocated to rainfed crop and crop pasture production systems, averaged over the past ten years, for all Relatively Homogeneous Farming Areas (RHFA) in the Province. Evaluation of these data resulted in an estimate that approximately 800 000ha of arable land in the Western Cape would be suited to rainfed winter cereal crop production systems.

Data and simple relational models were identified from international and local literature that predicted the effects of thermal time (growing degree days – GDD), photothermal units (PTU) and seasonal water supply (SWS) on the growth and development of canola. The potential effects of these environmental variables on the growth and development of canola were quantified using a GIS modelling framework for each RHFA in the Western Cape.

Growing degree days

With few exceptions there were sufficient accumulated growing degree days (GDD) for medium maturity type conventional canola cultivars to achieve 50% flowering within 90 days from planting in all rainfed cultivated areas suited to winter cereal crop production systems in the Western Cape. This result is based on a planting date of 1 May in Region 1 and 15 April in Region 2.

Photothermal units

Accumulated photothermal units (PTU) for each of three growth phases identified for canola i.e. Phase 1 – planting to 50% flowering; Phase 2 – flowering; Phase 3 – post flowering to physiological maturity, were quantified for medium maturity type conventional canola cultivars in each RHFA. The results indicated that almost all of the cultivated lands used for rainfed winter cereal crop production systems received sufficient PTU for Phases 1 and 2 but that insufficient PTU were available for canola plants to complete their physiological development to achieve optimum production during Phase 3 – a 30-day period in our model. However, under ideal temperature and soil water availability conditions during Phases 1 & 2, the end of flowering stage is likely to be completed in a shorter time frame than the 45 days allocated to flowering in our modelling of the physiological development of the canola plant. Under such conditions there should be sufficient PTU to allow canola to achieve normal (non-stressed) physiological maturity during Phase 3 in most RHFAs.

These observations on accumulated PTU are based on average long-term temperature data. However, most grain producing regions of the Western Cape experience extended periods of dry, hot weather during the growing season. Often these extended dry, hot periods occur during Phase 1 (in May) and/or in August/September (late Phase 2 and early Phase 3). Therefore, whilst there are sufficient PTU available, the potential physiological development of canola could be often be limited by excessive temperatures and/or by available soil water which, in turn, tend to extend the number of days required for each growth phase. In addition, the physiological development of the canola plant is often limited towards the end of Phase 3 through temperature- and/or water- stress induced physiological maturity thus limiting the potential of the plant to utilize available PTU.

In general, however, our modelled results indicate that, on their own, accumulated GGD and PTU are not limiting factors to the growth and development of canola in the rainfed crop a pasture production areas of most RHFAs in the Western Cape

Seasonal water supply

Seasonal water supply (SWS) is recognised as the main environmental factor influencing canola production. Predicted canola production, based on a SWS x WUE model, in the present study did not provide, in comparison with known long-term potential yields, realistic estimates of canola yield potential across all RHFAs. However, the range in predicted yields from “low”, through “intermediate” to “high” production potential provided a useful guideline towards allocating the RHFAs into “low”, “intermediate” and “high” canola production potential categories. The total area that was estimated to be suited to canola production based on SWS-yield predictions was about 875 000ha which is greater than the area of cultivated land suited to cereal grain production systems suggested from the DAWC and PICES data sets.

The one major environmental variable that has a major influence on the production potential of all crops that was not taken into account in our model was the soil. This was due to the fact that sufficiently detailed regional soil classification data were not available for the purposes of this study. We therefore relied on the inputs of experienced field-crop advisors from the grain producing regions to assist in verifying, and adjusting where necessary, the area of each RHFA suited to canola production that resulted from the SWS-based yield predictions.

Identified areas suited to canola production in the Western Cape

Integration of local experience with the modelled effects of environmental factors on canola growth and development yielded the final outcomes of our efforts towards identifying areas suited to canola production in the Western Cape.

The total area of cultivated land suited to rainfed canola production in the traditional winter cereal production sub-Regions of the Swartland and the Southern Cape is estimated at 743 500ha. We estimate that thirty seven per cent of this area (273 000ha) has high production potential, 56% (42 000ha) has intermediate production potential, and 7% (50 300ha) has low production potential. Division of the RHFAs into the low, intermediate and high production potential categories is debateable. This is particularly so for the RHFAs located in Region 2 due to the gross underestimation of actual long-term yields by the SWS-yield prediction of our modelling efforts. The Hoffmann expert consensus data provided some guidance but more area-based, field-scale yield data would be required to improve allocation of RHFAs (or portions of RHFAs) into the production categories.

“New” production areas with intermediate to high production potential totalling approximately 19 000ha have been identified whilst “marginal” production areas that include areas of low, intermediate and high production potential total approximately 24 000ha.

Areas allocated to the miscellaneous production areas total about 12 000ha and are included in this category due to the small size of lands, poor soils and high risk associated with canola production.

We recommend that canola production should be promoted on the estimated 743 500ha of traditional crop and crop/pasture production areas. We further recommend that additional detailed investigation of the occurrence, timing and duration of frost during the growing season, and/or the physical and chemical suitability of soils in the many RHFAs listed in the “new” and marginal areas as well as in the “miscellaneous” areas is required before canola production could be promoted in these RHFAs.

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Introduction

Rain-fed crop and crop/pasture production systems in the Western Cape are confined almost exclusively to the Coastal Renosterveld Veld Type which is located in the coastal lowland regions of the Western Cape Province (Figure 1). The soils are mainly shales of the Malmesbury and Bokkeveld complexes, tend to be very shallow (< 500mm deep) with poor vertical drainage, and are prone to erosion and soil capping. The soils have relatively high fertility when compared to the deep sandy soils of the Western Cape but intensive cropping and pasture systems require inputs of lime, P, K, N & trace elements.

Despite their poor physical characteristics, the relatively high fertility of these shale derived soils and the gently undulating topography has resulted in approximately 93% of the Coastal Renosterveld being transformed for various forms of agricultural production since the Cape was settled in the mid-1600s – but mostly for use in rain-fed cereal grain and pasture production systems. While cereal crops and pastures are grown on deep sandy, aeolian soils found mainly adjacent to the west and south coast regions, these areas have low production potential with associated high production risk.

All available arable land in the Western Cape Province has been cultivated at some time since the mid-1600s, and much of the land that was cultivated was not necessarily arable or had low production potential. This has resulted in large areas of previously cultivated land now lying fallow. Satellite imagery that shows cultivated areas i.e. land that has been transformed from natural vegetation, tends to over-estimate the areas available for cultivation.

Canola was introduced into the rain-fed cereal grain producing regions of the Western Cape Province during the 1990's. The areas planted to canola increased from about 16 000ha in 1999 to about 44 000ha in 2004. Thereafter the area planted to canola declined to below 35 000ha until the 2011 and 2012 seasons when 43 200ha and 42 500ha respectively were planted (Crop estimates Committee - 2012). Many questions have been asked regarding why the area planted to canola in the Western Cape seems to have reached a plateau of about 40 000ha. Despite the success that many producers have had with canola and the numerous research projects that have shown the positive effects of including canola in their production systems, many farmers remain reluctant to plant the crop.

Most farmers cite the financial risk associated with producing canola in the Western Cape and it is this risk (perceived or otherwise) that must be addressed in order to promote increased production of canola in this winter rainfall grain producing region. Production risk is a function of many interacting factors, the most important of which in the relatively low rainfall zones of the Western Cape is soil moisture availability during the growing season. Soil moisture availability is dependent on the amount and timing of rainfall, the moisture holding capacity of the soils, local climatic factors such as air temperature and wind, as well as agronomic interventions such as the maintenance of between-season soil cover, weed-free fallow and minimum soil disturbance when establishing the

crop. Other factors involved in production risk include: soil potential; input costs; canola price and agronomic practices such as controlling weeds, pests and diseases; sowing date, fertilization and harvesting – all of which can influence final yield. These production risks are experienced (and perceived) by producers who farm in similar agricultural environments such as in Western Australia (see Farré et al 2007).

Putting the risks (real or otherwise) of canola production to one side one must ask the questions:

1. What is the environmental (climate and soils) potential for canola production in the Western Cape; and
2. What is the total area that could be planted to canola with due consideration for identifying areas of low, medium and high production potential?

The objective of this project is to provide quantitative answers to these questions by:

- Presenting a short overview of environmental requirements for the production of spring canola in a temperate winter rainfall region,
- Using these environmental requirements within a GIS modelling framework to identify and delineate areas of low, medium and high production in the Western Cape,
- Conduct a verification exercise using historical data on areas cropped with cereal grains to determine the extent to which the GIS exercise effectively represents areas suited to canola production in the Western Cape.

Methodology

Review literature and consult researchers, technicians and advisors

The authors undertook a focused literature review to identify those environmental factors that most sensitively influence the growth, development and production potential of canola. Meetings were held with several researchers, technicians and advisors to verify procedures applied in determining areas suited to canola production in the Western Cape and the modelled estimates of canola production potential of the identified areas.

Development of maps showing areas suited to canola production

GIS modelling quantified the spatial variation in environmental variable that affect canola growth and development. The principle of the spatial approach used in developing this model is based on the concept of “raster” analysis. A raster is a continuous grid of values, for which each pixel within the grid contains a value, for example rainfall or temperature. This is a commonly used approach for spatial analysis and image processing, whereby each pixel of the grid can be treated as a number in an algebraic expression and computed against any other pixels in precisely coincident geographical space.

Raster grids for temperature and rainfall have been derived by various academic institutions in South Africa by interpolating values between observations by various regression techniques. The model process can be carried out step-wise in the ArcGIS environment, or programmatically structured in the Modelbuilder module, which allows the complete model to be run. Diagram 1 illustrates the

Modelbuilder flow scheme for the Water Use Efficiency model, which spatially implements the equations described in section 4(c).

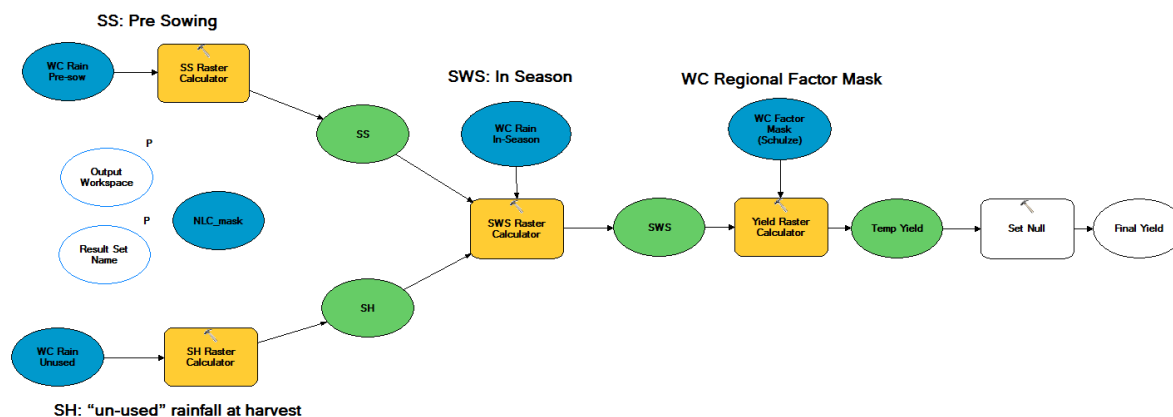


Diagram 1. Modelbuilder flowchart of GIS processes.

1. Relatively homogeneous farming areas (RHFAs)

The Western Cape Province has been divided into Relatively Homogeneous Farming Areas (RHFAs) (Department of Agriculture Western Cape, 1990) and maps showing the RHFAs are available in digitized format from the Resource Utilisation Institute of the Western Cape Department of Agriculture. These RHFAs were used as a framework within which potential areas for canola production could be identified and canola production potential could be estimated using modelling processes in a GIS platform.

The RHFAs were defined by the following guideline (translated from the Afrikaans)
A defined region where the main agricultural activities practiced, or which realistically could be practiced, are common to most farm enterprises and within which the pertinent soil patterns and climate factors do not vary sufficiently to influence farming practices and production potential.

The Department of Agriculture: Western Cape (WCDA) developed a series of books or manuals known as Regional Development Plans (RDPs) (or “*Streeksontwikkelingsplanne*” in Afrikaans) commencing during the 1970s (Department of Agriculture Western Cape, 1990). A manual was produced for each of 5 sub-regions of the province and chapters within each manual referred to specific agro-ecological zones known as relatively homogeneous farming areas (RHFAs). The boundaries of these RHFAs were initially determined from 1:250 000 topocadastral map sheets by regional extension officers and scientists, drawing on a number of unpublished analyses and reports, and discussion groups. Later, the National Land Type Survey (ARC-ISCW Land Type Survey Staff, 1972) was used to refine the boundaries. Considering the original workers did not have access to GIS, satellite imagery and digital terrain models, the resulting product is a remarkable testimony to the skill and dedication of those agriculturists involved. Subsequent small modifications and error corrections have been carried out by M Wallace and co-workers at the Resource Utilisation Institute, WCDOA.

2. Cultivated areas of Western Cape used for rain-fed crop production

A digitized map based on a data set that was compiled in 2010 and identifies all fields that are currently under cultivation (and have been for the past 10 years) in the Western Cape was provided by the Resources Utilization Institute of the WCDA. Each cultivated field in the province was accurately mapped for the purposes of the PICES project. Attribute data attached to these fields identify them according to a number of defined classes (based on photo-interpretation by experienced GeoTerralmage staff). Thus cultivated areas used for forestry, vineyards, orchards, urbanization and **irrigated** crops, vegetables, pastures and fodder crops, were removed from the data set. The remaining cultivated areas, that we assume to be used mainly for rain-fed crop and pasture/fodder production, were over-laid onto the RHFA map, which allowed the area of each RHFA that had been cultivated to be determined.

3. NDVI map of wheat production potential

An additional data set was obtained from the Resources Utilization Institute of the DAWC that provides an estimate of biomass production potential for rain-fed cereal crops and pastures in the Western Cape. This was done by developing a Normalised Difference Vegetation Index (NDVI) map showing the average NDVI for rain-fed cereal crops and pastures, during August, based on 10 years of NDVI data (2001 to 2010). Previous research has shown that NDVI for wheat at anthesis is strongly correlated ($r^2 = >0.7$) with total dry matter and grain yields of wheat (Aase & Siddoway 1981).

The NDVI for rain-fed cereal crops and pastures was overlaid on the previously identified cultivated areas of each RHFA providing an estimate of the potential area available for cereal and pasture production and the (relative) range in production potential for the Province as a whole, and within each RHFA.

4. Modelling environmental factors that influence canola production

Two main rain-fed crop production regions were identified for the purposes of this study: Region 1 included the Swartland, and Region 2 which included the southern Cape. The division of these two Regions was done on the basis of the proportion of annual rainfall that occurs during the growing season (April to October) and local experience on the timing of planting and harvesting dates (Agenbag et al, pers. com.). Because of this division several RHFAs normally associated with the Southern Cape were allocated to Region 1 (as part of the Swartland production area). The affected RHFAs were Botrivier (RHFA 12) Caledon Ruens (RHFA 16), Riviersonderendvallei (RHFA 74) and Villiersdorp/Vyeboom (RHFA 95).

The determination of areas in the Western Cape Province that are suited to canola production was based on the use of models extracted from literature and local experience. It was assumed that canola could be produced where wheat is produced (Potter et al, 1999; Agenbag et al, pers. com.). However, the risk associated with canola production differs from that of wheat. For example, due to its larger seed and fibrous/adventitious root system, wheat is more tolerant of poor moisture availability at and subsequent to planting than canola (which has a small seed and a tap root system). Canola also has a lower water use efficiency (WUE) than wheat (Robertson and Kirkegaard 2005, Bowman & Scott 2009) which limits its potential in areas of low rainfall where wheat can be produced. We therefore quantified important environmental requirements

for canola production within each of the RHFA. These were identified from the literature (Appendix 1) viz. temperature – calculated in terms of growing degree days (GDD); photothermal units (PTU) – GDD in combination with day-length; and season water supply (SWS).

Because of the pixel-by-pixel nature of the spatial computation, the values derived for GDD, PTU and SWS can vary across any zone, as would be expected in reality. The tabular data presents the spatial aggregation of values for the zones, and thus the in-zone variation is not evident. This does imply that some small variation between spatial algebra and tabular algebra results, per zone, may be evident, as a result of the averaging of this spatial variation. The reader is referred to the mapped representations for closer examination of within-zone variation in values.

a. Growing degree days (GDD)

Whilst GDD are usually calculated to determine thermal time from planting to 50% flowering, accumulated GDD are also used to calculate accumulated photothermal units (PTU) (Appendix 1). In the current study accumulated GDD were calculated from planting date to 50% flowering to allow for comparisons of GIS modelled GDD against locally available, site specific data sets for the same time period (Lombard 2011), and to allow for the calculation of PTU for each of the three growth phases identified for canola in each RHFA.

Accumulated monthly average GDD were calculated for each RHFA for each of three growth phases in the development of the canola plant. The growing phases were:

1. Planting to 50% flowering (Phase 1)
2. 50% flowering to end of flowering (Phase 2)
3. End of flowering to physiological maturity (Phase 3)

In consultation with local researchers (Agenbag et al pers. com.) calendar dates were allocated to the start and end of each of the growth phases within each of Regions 1 & 2 (Table 1).

Table 1 Calendar dates defining the start and end of each growth phase in each of two canola production regions

Growth phase	Region 1	Region 2
Phase 1	1 May to 31 July	16 April to 15 July
Phase 2	1 August to 15 September	16 July to 31 August
Phase 3	16 September to 15 October	1 September to 30 September

The accumulated monthly average GDD for each growth phase was calculated as follows:

$$\text{GDD} = (T_{\max} + T_{\min})/2 - T_{\text{base}}$$

where:

T_{\max} = Long-term mean monthly maximum temperature for month_x

T_{\min} = Long-term mean monthly minimum temperature for month_x

T_{base} = 0°C

month_x = Calendar month_x

Average daily GDD were calculated for each calendar month_x and then used to determine accumulated GDD (°Cd) for each of the growth phases listed in Table 1. In consultation with Agenbag et. al. (pers. com.) it was decided, for the purposes of this study, the duration of each growth phase should be standardised at: Phase 1 = 90 days; Phase 2 = 45 days; and Phase 3 = 30 days

Long-term temperature data were accessed from the Centre for Geographic Analysis, Stellenbosch University. Spatial masking methodology was used to select temperature and GDD values in the previously identified rain-fed cultivated areas only. Accumulated GDD were mapped and tabulated in GIS.

- b. Photothermal units (PTU) – refer to the literature review for detail on the effect of photothermal units on canola production (Appendix 1). Spatial masking methodology was used to select PTU values in the previously identified rain-fed cultivated areas only. Accumulated PTU were mapped and tabulated in GIS.

Using the same calendar dates as were used for defining the growth phases in the calculation of GDD (Table 1) long-term average accumulated PTU were calculated for each growth Phase within each RHFA as:

$$PTU_i = GDD_i \times H_i$$

where

GDD_i = long-term average accumulated GDD for growth phase_i

H_i = Average day length for growth phase_i

The units of PTU are expressed in terms of thermal time (°Cd) x day length (hrs) or °Cd.hr

- c. Seasonal water supply (SWS)

Long-term monthly rainfall data were used to calculate seasonal water supply (SWS) for each RHFA according to the formula presented by Robertson and Kirkegaard (2005) and Bowman and Scott (2009). Spatial masking was used to exclude non-cultivated areas of each RHFA. The formula was based on the approach published by French and Schultz (1984). Note that Robertson and Kirkegaard (2005) and Bowman and Scott (2009) stress that this calculation provides a rough estimate of canola production and is constrained by not accounting for other sources of water loss such as surface run-off from rainfall, and deep drainage below the rooting depth of the crop. However, the model has been applied here in the absence of local or internationally developed models for which suitable parameters have been produced that account specifically for the Western Cape soil/water/plant interface.

Rainfall for each RHFA was calculated from long-term monthly interpolated rainfall that was based on Schulze et.al. (2008). Schulze's group at UKZN pioneered a methodology for the interpolation of rainfall in South Africa, resulting in data that has become the "standard" input for spatial climate-based modelling in SA. The accuracy of the data is unavoidably a function of the distribution or density of rainfall stations from which the interpolations can be made in any region. There were few rainfall recording stations available in large areas of

the central and eastern Ruens (Region 2), which means that the actual variation in rainfall across the region may not be well expressed in the spatial data currently available. It is hoped that the Water Research Commission may update these data in the near future.

Together with an estimate of WUE, SWS provides a rough estimate for canola production potential of a specified area.

The growth Phases identified for each of Regions 1 & 2 defined the rainfall periods used to derive estimates of SWS . SWS was calculated for each RHFA within each of Regions 1 and 2 as:

$$\text{SWS} = (\text{in-crop rainfall}) + (\text{soil water at sowing}) - (\text{soil water at harvest}) - 120$$

where

in-crop rainfall = total rainfall from planting to physiological maturity of the crop

soil water at sowing = (fallow season rainfall-80) x 0.5, where 0.5 varies from 0.4 to 0.6 depending on the timing and amount of rainfall – NOTE: we used the default of 0.5 for this exercise

soil water at harvest = (post-flowering rainfall -50) x 0.5, where 0.5 can vary from 0.5 to 1.0 in wetter locations and from 0.2 to 0.5 in drier locations – NOTE: we used the default of 0.5 for this exercise

and 120 is the x axis cut-off of the total in-season rainfall below which zero canola production is expected (Robertson and Kirkegaard 2005). Thomas (2012) suggests a similar cut off stating that: “the first 100 mm go to building the plant factory”.

Note that where a negative value was calculated for SWS a value of 0 was recorded

In consultation with local researchers (Agenbag et. al. pers com.) calendar dates were allocated to the start and end of each rainfall period within each of the two crop production Regions (Table 2).

Table 2 Calendar dates defining the start and end of three periods used to estimate soil water supply in each of two crop production regions

Rainfall and soil water	Region 1	Region 2
In-crop rainfall	1 May to 15 Oct	15 April to 30 Sept
Soil water at sowing	1 Jan to 30 April	1 Jan to 15 April
Soil water at harvest	16 Sept to 15 Oct	1 Sept to 30 Sept

For the purposes of presentation and discussion of the results, SWS calculations for RHFAs 12 (Botrivier), 16 (Caledon Ruens), 74 (Riviersonderendvallei) and 95 (Villiersdorp/Vyeboom) were listed under Region 2.

5. Determination of areas suited to canola production

Geographic information system (GIS) technology was used to overlay (in map and table format) calculated GDD and PTU for each of the three growth phases and for the growing season onto the previously developed maps showing wheat production potential of each RHFA. These

overlays provide an insight regarding whether or not sufficient GDD and PTU are available for the canola plant to complete its physiological growth requirements in specific RHFA and thus indicate the extent to which GDD and /or PTU may limit canola production potential within a RHFA.

6. An estimation of the production potential of canola in the Western Cape
Maps showing the estimated production potential of canola in the Western Cape Province were developed using GIS technology. The production potential was calculated for each RHFA according to the formula presented by Robertson and Kirkegaard (2005) and Bowman and Scott (2009):

Canola yield = SWS x WUE

where

- i. SWS = seasonal water supply as calculated in 4c above
- ii. WUE = water use efficiency of the crop (for canola this ranges widely with a median value of 11 kg/ha.mm and a general range of 8 to 15 kg/ha.mm, where a WUE of 15 represents the “water limited potential” for canola production.

Discussions with various researchers and experienced advisors confirmed our assumption and understanding that the inherently higher organic matter content of soils in Region 2, together with milder climatic conditions, would potentially provide for improved WUE in Region 2 compared to Region 1 (de Clercq and Hoffman pers. com.). In addition, de Clercq (pers. com.) stated that the inherently higher salt concentrations that pertain in the soils of the Swartland areas of Region 1 compared to Region 2 would potentially add to the lower WUE of crops in those parts of Region 1 compared to Region 2.

Two WUE values were used to calculate canola production potential in each RHFA from the formula presented in 6 above and based on Robertson and Kirkegaard (2005) viz.

- 11 kg/ha.mm – average value over all data sets, and
- 15kg/ha.mm – for seasons of favourable water distribution.

7. Estimating areas currently planted to rain-fed annual crops and perennial and annual pastures
It is important to remember that the areas under cultivation in the W/Cape (and in SA in general) declined dramatically when the country moved from a Government legislated single channel marketing system for grain crops, import tariffs and farm subsidy schemes to a free market system where farm produced commodities were exposed to international prices and competition. The area currently under cultivation therefore represents those areas that have the potential to produce rain-fed crops and livestock products at a profit in the current economic climate. Data that provide estimates of the areas under rain-fed cultivation were obtained from the WCDA 1000-point surveys and from the National Crop Estimates Committee (NCEC).

WCDA 1000-point survey data

The most recent 1000-point survey (TPS) data sets were used. Cultivated lands and areas planted to various grain crops and pastures were surveyed during the winter months of 2003

and 2004 in the southern Cape and the Swartland respectively. These data were collected by extension staff who were required to drive along pre-determined routes within selected RHFA and to record the land-use in a camp on either side of the road at 500m intervals along the route. Land-use was classified into the following units: non-arable (includes drainage lines, farm roads and farm yards), veld, wheat, barley, oats, triticale, canola, lupine, fodder cereals, lucerne, medics, grasses, old lands, fallow lands, "other", perennial orchards, and irrigated lands (van Rooyen pers com).

The number of observations for each land use in the RHFA was expressed as a percentage of the total number of observations for that RHFA. The net area of land in each RHFA available for agricultural use (i.e. roads, buildings and urban areas excluded) was then multiplied by the estimated percentage occupied by each of the land-use units to provide an estimate of the total area allocated to a land-use type in each RHFA. These data were then used to provide an estimate of the total area under cultivation that was allocated to rain-fed crop and pasture production in the Western Cape.

The companies SiQ and GeoTerralmage (GTI) together with the Agricultural Research Council and the Department of Agriculture, Forestry and Fisheries (DAF&F), form a consortium responsible for the estimation of annual crop yields on an annual basis, by means of a statistical sampling technique. Their Producer Independent Crop Estimate Systems (PICES) data provided useful insight into the distribution of cultivated land. The PICES data for the Western Cape showed the areas allocated to the production of wheat, barley and canola for the period 2000 to 2012. Initially PICES data showing the areas allocated to wheat, barley and canola (calculated as the average for the 2003 and 2004 PICES data sets) were compared to the TPS data for 2003 and 2004.

No independently collected data estimating the area under rain-fed pasture and small grain fodder crops were available for 2003 and 2004. However, data were available, from the PICES data set, of the areas under rain-fed lucerne, medic/clover and small grain fodder crops for the 2010 to 2012 seasons. It was therefore decided to use the 2012 PICES estimates for areas planted to wheat, barley and canola, together with the 2012 PICES estimates of areas planted to lucerne, medic/clover and small grain fodder crops, and compare those estimates with the combined 2003 (southern Cape) and 2004 (Swartland) TPS estimates. These comparisons allow for general conclusions on cultivated land currently used for rain-fed crop and pasture production in the Western Cape Province.

Data from the TPS and PICES surveys thus provide a basis against which the current study's predictions of areas suited to canola production could be compared.

8. PICES spatial analysis of areas planted to canola in the Western Cape - 2007 to 2011
An additional data set showing a sample of the verified location of canola plantings in the Western Cape over a five year period (2007 to 2011) was obtained from PICES. These data provide an ideal opportunity to determine the extent to which areas suited to canola production predicted in the current study coincide with the areas that were actually observed to be planted to canola.

Results

1. Production Regions

Our division of the Western Cape Province into rain-fed crop and pasture Production Regions (Regions 1 and 2) is presented in Figure 2. These regions were based mainly on the proportion of annual rainfall that occurs within a Region for the period April to October. Region 1 (Swartland and neighbouring west coast cropping areas) generally receives the first significant winter rains approximately two weeks later than Region 2 (southern Cape). Timing of rainfall thus impacts on planting date, and on the physiological response of plants during the growing season to factors such as minimum and maximum day temperatures, day-length and seasonal water supply. Note that the planting dates for the four RHFAs (RHFA Nos 12, 16, 74 and 91), that were placed within Region 1 for the purposes of determining the effects of temperature and day-length on plant physiological processes, are similar to the planting dates used in the farming areas of Region 1. Note also that Region 2 groups farming areas of the Little Karoo, the Karoo and the Garden route together with the traditional grain producing farming areas of the southern Cape.

2. Relatively Homogeneous Farming Areas (RHFA)

The RHFAs for the Western Cape are presented in Figure 3 and alphabetically for each of Regions 1 and 2 in Tables 3 & 4 respectively. We have numbered each RHFA according to its alphabetical ordering to allow for ease of comparison between the Tables and Figures and to assist with sorting the data sets. Ninety five RHFAs are listed and the total area of each RHFA is presented in the Tables.

3. Cultivated areas of Western Cape used for rain-fed crop and pasture production

The digitized map compiled by PICES in 2010 showing all areas identified as having been cultivated for rain-fed crop and pasture/fodder production in the Western Cape Province over the preceding 10 years is presented in Figure 4. The area of each RHFA that had been cultivated for rain-fed crop/pasture production systems in each of Regions 1 and 2 are presented in Tables 3 and 4. The estimated total areas cultivated in Region 1 and Region 2 were 971 976ha and 676 065ha respectively, resulting in a total cultivated area for rain-fed crop and pasture/fodder production in the Province of 1 648 041ha.

Many of the cultivated areas identified in the survey are located in low rainfall zones and/or on sandy or shallow soils, including "strip field" cultivation located in the north western part of Region 1 and cultivated lands in the Karoo and Little Karoo parts of Region 2 (Figure 4). While many of these cultivated lands were used until the late 1900s for low-input cereal grain production they are now used mainly in low-input pasture or fodder crop production systems. However, whilst large proportions of the cultivated areas of the Western Cape are not suited to rain-fed crop production, for the purposes of the current study it was decided to use all the cultivated areas identified in the survey as a basis from which areas potentially suited to canola production could be identified.

4. NDVI map of biomass production potential

The NDVI map providing an index of the 10-year average biomass production potential-for rain-fed cereal crops and pastures in the Western Cape is presented in Figure 5. Since the Normalised Difference Vegetation Index was based on imagery collected during August when wheat is at the anthesis stage of development it also provides a surrogate for wheat production potential (Aase & Siddoway 1981). The NDVI data (Figure 5) clearly illustrate a) where rain-fed cereal crops and pastures were (on average) produced in the Western Cape for the period 2001 to 2010, and b) the relative range in production potential (from low to high) for each RHFA within each of Regions 1 and 2.

5. Modelling environmental factors that influence canola production

a. Growing degree days (GDD)

The accumulated GDD for each of the three growth phases we identified for canola production in the Western Cape are presented in Figures 6, 7 and 8 respectively. Accumulated GDD for the growing season are presented in Figure 9. The figures provide a spatial representation of the range in GDD available for each growth Phase for the Western Cape as a whole and, on closer inspection, differences in available GDD among the RHFAs.

The accumulated GDD for each of three growth phases for canola are presented in Tables 5 and 6 for each RHFA in Regions 1 and 2 respectively. Accumulated GDD for each RHFA are ordered according to increasing accumulated GDD in Phase 1. In Region 1 the GDD range from 880 to 1407 °Cd, 459 to 707 °Cd and 387 to 558 °Cd for Phases 1, 2 and 3 respectively. In Region 2 the GDD range from 954 to 1434 °Cd, 419 to 642 °Cd and 357 to 473 °Cd for Phases 1, 2 and 3 respectively.

b. Photothermal units (PTU)

The accumulated PTU for each of the three growth phases we identified for canola production in the Western Cape are presented in Figures 10, 11 and 12 respectively. Accumulated GDD for the growing season are presented in Figure 13. The figures provide a spatial representation of the range in PTU available for each growth phase for rain-fed cultivated lands in the Western Cape as a whole and, on closer inspection, differences in available PTU among the RHFAs.

The accumulated PTU for each of three growth phases for canola are presented in Tables 7 and 8 for each RHFA in Regions 1 and 2 respectively. Accumulated PTU for each RHFA are ordered according to increasing accumulated PTU in Phase 3. In Region 1 the PTU range from 8854 to 14302 °Cd.hr, 5102 to 7756 °Cd.hr and 4752 to 6844 °Cd.hr for Phases 1, 2 and 3 respectively. In Region 2 the PTU range from 9937 to 14639 °Cd.hr, 4435 to 6710 °Cd.hr and 4189 to 5534 °Cd.hr for Phases 1, 2 and 3 respectively.

c. Seasonal water supply (SWS)

Seasonal water supply (SWS) is calculated as a function of “in crop” rainfall from planting to harvest **plus** soil water at planting **minus** excess water at harvest – refer to methods section for detail. The SWS as estimated from extrapolated, long-term rainfall data sets for each RHFA in Regions 1 and 2 are presented in Tables 9 and 10 respectively. Accumulated SWS

for each RHFA are ordered according to increasing SWS estimates. Note that the calculation of SWS involves subtracting the first 120mm of “in-crop” seasonal rainfall. This is based on research data that indicate an expected zero yield of canola if the “in-crop” rainfall (planting to harvest) is less than 120mm (Robertson and Kirkegaard, 2005).

The SWS calculated for RHFAs in Region 1 ranges from -60mm to 741mm with most traditional grain producing regions in the range 59mm (RHFA No. 76) to 300mm (RHFA No. 21). As expected SWS is much lower in Region 2 ranging from -81mm to 260mm with most of the traditional grain producing areas in the range 36mm (RHFA No. 29) to 132mm (RHFA No. 16).

6. Estimating canola production potential in the Western Cape

For the purposes of estimating canola production potential from SWS and WUE, the four RHFAs that were allocated to Region 1 viz RHFAs 12, 16, 74 and 95 because of rainfall distribution and planting date, were reallocated to Region 2 due to their location in a Region with milder temperatures and higher soil organic matter content than Region 1 which we assumed would result in a higher WUE factor for Region 2 than Region 1.

Yield predictions based on the median WUE value of 11 kg/ha.mm appeared realistic for Region 1 but not for Region 2. Since our objective aimed to provide estimates showing regions of “low”, “medium” and “high” canola production potential we also applied a WUE of 15 kg/ha.mm which yielded an improved yield estimates for Region 2.

Data presented in the figures and tables are based on WUE estimates of 11 and 15 kg/ha.mm for RHFAs in Regions 1 and 2 respectively. The results should be interpreted in relative rather than absolute terms, for each Region separately, to identify areas (RHFAs) of “low”, “medium” and “high” canola production potential.

In several instances the spatial variation in SWS across cultivated areas of individual RHFAs included negative values which resulted in a 0 kg/ha yield estimate for those cultivated areas. Therefore the area of cultivated land within each RHFA with an estimated canola production potential of 0 kg/ha was subtracted (on a pixel by pixel basis) from the total area of cultivated land in each RHFA presented in Figure 4 and Tables 3 & 4.

Estimated canola production potential is presented in Figure 14 which provides a spatial representation of the predicted range in canola production potential for rain-fed cultivated lands in the Western Cape as a whole and, on closer inspection, differences in canola production potential within and among the RHFAs. Estimates of the average canola production potential for each RHFA in Regions 1 and 2 are presented in Tables 11 and 12 respectively. Yield estimates for the RHFAs in Region 1 vary from 0 to 8151 kg/ha with the 8151 kg/ha estimate for Elgin/Grabouw being an obvious outlier. Canola yield estimates for the traditional grain producing regions of Region 1 range from 656 kg/ha (RHFA 76) to 3210 kg/ha (RHFA 85).

Yield estimates for the RHFAs in Region 2 vary from 0 to 3895 kg/ha. The six highest yield estimates are for RHFAs not usually associated with grain production viz. RHFAs 80, 38, 20, 95

and 11. Canola yield estimates for the traditional grain producing regions of Region 2 range from 555 kg/ha (RHFA 29) to 1961 kg/ha (RHFA 16).

7. Estimation of areas currently cultivated and areas planted to rain-fed annual crops, and perennial and annual legume pastures in the Western Cape
 - a. WCDA 1000 point survey data

Results of the 1000-point survey conducted by the Western Cape Department of Agriculture in 2003 and 2004 are presented in Section A of Table 13. A total area of 1 455 921ha was estimated to have been cultivated most of which was planted to rain-fed crops, legume pastures and fodder crops in 2003 (southern Cape) and 2004 (Swartland). An estimated 530 004ha were planted to wheat, barley and canola although this appears to be an over-estimate when compared to the PICES data for the same crops in 2003/2004 (Table 13B).
 - b. PICES data sets

PICES estimates of areas planted to wheat, barley and canola (average for 2003 and 2004), and planted to wheat, barley, canola, small grain feed and legume pastures in 2012 in the Western Cape are presented in Section B of Table 13. The estimated total areas planted to wheat, barley and canola in 2003/2004 (average for the two years) and in 2012 were 453525ha and 390500ha respectively. Note the large increase in areas planted to legume pastures as estimated in the PICES data set (441400ha) compared to the 250559ha of legume pasture estimated in 2003/2004 in the TPS data set (Table 13A).

The PICES spatial analysis of areas planted to canola in the Western Cape from 2007 to 2011 is presented in Figure 15. The sampling procedure included aerial surveys and land-based verifying of the location and crop identification of each sample point and clearly shows the distribution of canola plantings in each of the two production Regions. In Region 1 canola has been planted mainly in RHFAs 27, 34, 36, 45 and 56. In Region 2 canola was planted mainly in RHFAs 13, 14, 16, 33, 55, 73 and 82 (Figure 15). Clearly canola has been planted mainly on the shale derived soils of the Coastal Renosterveld Vegetation Type shown in Figure 1. RHFA with deep sandy soils and or low SWS have been avoided. Furthermore, canola has been planted throughout the traditional crop and crop/pasture production areas of the Swartland and Southern Cape sub-Regions suggesting that canola is well adapted to these production regions.

Discussion and further analyses of results

1. Identification of areas suited to canola production based on estimates of cultivated land in the Western Cape Province

We used the RHFAAs identified for the Province as a basis for presenting the outcomes of this study. The WCDA thousand point survey (TPS) data sets obtained in 2003 and 2004 were restricted to the two farming sub-regions viz. the Swartland and the South Coast where, for all practical purposes, most of the Province's grain crops have been and currently are produced within continuous cropping and crop/pasture production systems. The results of the TPS estimate that a total area of 1 455 921ha were cultivated in the Swartland and the South Coast during 2003 and 2004 (Table 13). Inspection of Table 13 indicates that cash crops were planted on about 640 000ha, fodder crops and pastures on 520 000ha, and 297 000ha were classed as old- or fallow lands.

A comparison of the TPS data of the total area of rainfed cultivated land in the Swartland and South Coast sub-regions of the Province (1 455 921ha – Table 13) against the PICES estimate of the total area of cultivated land in the whole Province used for rainfed crop and pasture production (1 648 041ha – Tables 3 & 4) suggests that about 88% of all cultivated land in the Province is to be found in the Swartland and South Coast sub-regions. However, comparison of the areas estimated to have been planted to wheat, barley and canola in the TPS data set (530 004ha) with the 2003/2004 PICES data for the same crops (453 525ha) suggests that the TPS data over-estimated the areas cultivated to those crops by at least 17% (TPS data do not consider cultivated areas outside of the Swartland and South Coast sub-regions). Reducing the total area estimated in the TPS data set by 17%, the TPS data indicates that 1 266 651ha were cultivated in 2003 and 2004.

Areas of cultivated land listed in the PICES data set for RHFAAs located within the South Coast and Swartland sub-Regions are presented in Table 14. The total estimated area of (1 215 465ha) is similar to the adjusted estimate of 1 266 651ha derived from the TPS data set.

The PICES estimate of 977 100ha for the total area planted to wheat, barley and canola, as well as small-grain feed and legume pastures in the Province as a whole in 2012 (Table 13), is considered to be the most accurate data currently available. If the estimated areas of fallow- and old-lands are excluded from the adjusted TPS estimates, the total cultivated area estimated by the TPS is 969 692ha. The PICES estimate of 977 100ha is thus similar to the TPS estimate which suggests that there is a limited amount of cultivated land outside of the boundaries of the Swartland and South Coast sub-regions that is currently allocated to rainfed crop and crop/pasture production systems. This statement is supported by the spatial data presented in the NDVI map showing areas of potential dry matter production as a proxy for wheat production potential in the Province (Figure 5). Figure 5 clearly shows that wheat production potential in the Western Cape lies almost exclusively in the Swartland and South Coast sub-regions, with relatively small pockets of land, that also have the potential to produce wheat, directly adjacent to the northern slopes of the Outeniqua mountain range, in the Breede river basin, and in the Ceres and Cedarberg mountains.

Not all cultivated land is necessarily suited to cash crop production. Inspection of TPS and PICES data in Table 13 indicates that approximately 40% of the total cultivated area estimated in each survey (with old-lands subtracted from the TPS total) is allocated to the cash crops: wheat, barley and canola. Assuming that 40% of the total area is planted to cash crops each year and that some form of rotation is practiced on all farms then it is estimated that about 80% of the cultivated land that is allocated to crop and crop/pasture production systems in the South Coast and Swartland sub-regions is suited to the production of cash crops under rainfed conditions. Applying this estimate to the PICES data for 2012 these data suggest that approximately 782 000ha of cultivated land in the Province would be suited to rainfed cash crop production. The next phase of our study therefore aimed to identify those environmental factors that would influence the production potential of canola within the those areas suited to cash crop production in the Western Cape and thus assess the areas suited to canola production.

2. Determining areas suited to canola production based on temperature, day-length, soil water supply and local experience

Long-term temperature and rainfall data sets were used within a GIS modelling framework to calculate growing degree days (GDD), photothermal units (PTU) and soil water supply (SWS) providing a range of values for each of the environmental variables for each RHFA. Results of the modelling procedures relate to long-term averages which, when interpreted, produces an expected “average” response of canola to each environmental variable. Moreover, the GIS modelling procedure interpolates point-based data that allows for estimation of the spatial variability of a variable (such as GDD) within and between RHFAs. While this variability is conveniently shown in graphical form in the figures this is not possible when presenting results for each RHFA in the tables. Tabulated results of the analyses of environmental variables are therefore presented as the average for that variable within each RHFA.

Since the equation used in relating phenological development of canola to accumulated PTU was based on three “mid-season” Australian cultivars of similar phenology (Kirkegaard et.al. 2012), general discussion of the results focuses on canola cultivars of the medium flowering group.

a. Growing degree days (GDD)

Growing degree days were calculated for each of the three canola growth phases identified for this study mainly to allow for the calculation of PTU (which will be discussed in the next section). However, it was also considered important to assess the accumulated GDD for each RHFA for the 90-day period from planting to 50% flowering against similar data presented in local and international studies as accumulated GDD has commonly been used to predict the vegetative development of canola (Lombard 2011).

Lombard (2011) reported that the number of days from planting to 50% flowering for the medium development group of conventional canola cultivars varied on average from 96 to 101 and 99 to 108 days at Langgewens (33°16'S -located in Region 1) and Tygerhoek (34°9'S - located in Region 2) for “early” and “late” planting dates respectively. Average “early” and “late” planting dates for the Langgewens site were between 1 May and 22 May whilst for

Tygerhoek these dates ranged from 19 April to 17 May. These planting dates and days to 50% flowering resulted in accumulated average GDD from planting to 50% flowering ranging from 1330 °Cd to 1450 °Cd at Langgewens and from 1300 °Cd to 1500 °Cd at the Tygerhoek site (Lombard 2011).

Robertson et.al. (2002) reporting on days from sowing to flowering for a range of canola cultivars at a range of latitudes state that the mean number of days to flowering across cultivars ranged from 68 to 91 days. Burton (2008) report that, at a site located at Horsham (36°41'S), the days to flowering ranged from 99 to 111 days for three canola cultivars: Monty, Rainbow and Dunkeld. They also reported on predicted thermal time (GDD) to flowering that ranged from 931 °Cd to 1179 °Cd for those three cultivars from a model that was based on phenological observation at trial sites located in Australia and Canada (Burton et.al. 2008).

Our GIS modelling shows, for the RHFA in which Langgewens is located (RHFA 56), a long-term average of 1232 accumulated GDD for the 90-day period from the beginning of May to end July (Table 5). Similarly, for the RHFA in which Tygerhoek is located (RHFA 82), there is a long-term average of 1316 accumulated GDD for the 90-day period from the middle of April to the middle of July (Table 6). These GDD data are similar in magnitude to the data presented by Lombard (2011) and considering that the Lombard (2011) accumulated GDD from planting to 50% flowering were based on an average of 10 more “days to flowering” and, on average, later planting dates, our GIS modelling of GDD from planting to 50% flowering is regarded an accurate reflection of accumulated GDD in RHFAs for both Regions 1 and 2 (Tables 5 and 6). Furthermore, with few exceptions, the accumulated GDD from planting to 50% flowering for all RHFAs in Regions 1 and 2 exceed those GDD values presented by Burton et.al. (2008) suggesting that accumulated GDD during Phase 1 of the phenological development of canola would not be limiting to canola production in these two regions.

All the RHFAs that are located in the traditional grain producing regions of the Province, as listed in Table 14, are highlighted in Tables 5 and 6. It is of interest to note that in Region 2 the accumulated average GDD available during Phase 1 of canola growth for all RHFAs traditionally used for grain production, exceeds 1270 °Cd (Table 6). By contrast the accumulated average GDD available during Phase 1 of canola growth for all the RHFAs located in the traditional grain production area of Region 1 (Swartland) is less than 1270 °Cd (Table 5). This is a function of the modelling where the modelled planting date for Region 1 was 14 days later than for Region 2 resulting in lower average daily temperatures for Region 2 during Phase 1.

Spatial presentation of the data in Figure 6 illustrates the regional variation of accumulated GDD from planting date to 50% flowering. The higher GDD available in the South Coast area of Region 2 than in the Swartland area of Region 1 is clear although, if it is accepted that more than 1200 °Cd would not be limiting to the phase 1 stage of canola development, there appears to be sufficient accumulated GDD for Phase 1 development of canola though out the Province. The lower accumulated GDD shown for the Caledon area (RHFAs 16, 25, 74 and 91) is, of course, due to the later planting dates used in the modelling process (Figure 6).

It is only in the mountainous regions that accumulated GDD for Phase 1 appear to be limiting (Figure 6). However, in areas that have sufficient cold units for vernalization to occur, then some arable areas within of the colder, mountainous regions may well be suitable for Phase 1

due to the lower accumulated GDD required following vernalization of developing canola seedlings during this phenological phase of plant growth (Burton, 2008). Moreover, the colder conditions during the 45 day flowering period (Phase 2), and the 30-day post flowering to physiological maturity period (Phase 3) as indicated by low accumulated GDD in these cooler mountainous areas, could have both negative and positive effects on canola production potential. In the absence of frost and with adequate soil moisture the cool conditions with increasing day-length during Phases 2 and 3 would benefit canola production whilst frost damage and water deficits during these phases would limit production potential irrespective of available GDD (refer to the GDD values presented for the Koue-Bokkeveld (RHFA 46) and Warm-Bokkeveld (RHFA 92) respectively (Table 5)).

b. Photothermal Units (PTU)

Our reference point for analysing the effect of the accumulated PTU calculated for each of Phases 1, 2 and 3 in each RHFA on canola growth and development is the linear model, developed by Kirkegaard et.al. (2012), relating the PTU to “percentage development to physiological maturity” (PDPM). The linear model is presented as follows:

$$PTU = -627 + 231 * PDPM \quad (r^2 = .97)$$

Data presented in Figure 2 in Kirkegaard et.al. (2012) were used to estimate PDPM at the end of each of the 3 Phases of development of canola used in our study, by comparing PDPM with the growth stage key values of Harper and Berkenkamp (1975) as follows:

Phase 1 – 50% flowering (growth stage 4.1)	PDPM = 55%
Phase 2 – end of flowering (growth stage 4.4)	PDPM = 70%
Phase 3 – physiologically mature (growth stage 5.5)	PDPM = 100%

The predicted accumulated PTU necessary to reach the end of Phases 1, 2 and 3 in our study are therefore:

$$\text{Phase 1: } PTU = -627 + 231 * 55 = 12078$$

$$\text{Phase 2: } PTU = -627 + 231 * 70 = 15543$$

$$\text{Phase 3: } PTU = -627 + 231 * 100 = 22473$$

Note that the units of PTU are expressed in terms of thermal time ($^{\circ}\text{Cd}$) x day length (hrs) or $^{\circ}\text{Cd.hr}$

PTU required for Phase 1 is thus 12078 $^{\circ}\text{Cd.hr}$, from end of Phase 1 to end Phase 2 is 3465 $^{\circ}\text{Cd.hr}$, and from end of Phase 2 to physiological maturity (end Phase 3) is 6930 $^{\circ}\text{Cd.hr}$.

Phase 1

Accumulated PTU for Phase 1 in all of the traditional grain producing RHFAs in Region 2 (Table 8) and almost all RHFAs in Region 1 (Table 7) exceed the accumulated PTU that is predicted to be required from planting to flowering. A notable exception is in the Caledon Ruens (RHFA 16) where the modelled late planting date, and inherently milder temperatures compared to the

Swartland area of Region 1, result in an estimated PTU of 11492 for the Caledon Ruens (Table 7).

Phase 2

Accumulated PTU for Phase 2 in all of the traditional grain producing RHFAs in Regions 1 and 2 (Tables 7 and 8) exceed the accumulated PTU that is predicted to be required for successful completion of the flowering phase by more than 2000 °Cd.hr. The excess accumulated PTU in the traditional grain producing RHFAs in Region 1 ranges from 2577 °Cd.hr (RHFA 91) to 3229 °Cd.hr (RHFA 45). The excess accumulated PTU in the traditional grain producing RHFAs in Region 2 ranges from 2300 °Cd.hr (RHFA 13) to 3245 °Cd.hr (RHFA 30).

Phase 3

Accumulated PTU for Phase 3 in all of the traditional grain producing RHFAs in Regions 1 and 2 (Tables 7 and 8) are **lower** than the accumulated PTU that is predicted to be required for successful completion of the post flowering to physiological maturity phase by more than 880 °Cd.hr. The deficit ranges from 880 °Cd.hr (RHFA 45) to 2058 °Cd.hr (RHFA 38) (Tables 7 and 8).

At face value these data suggest that the low accumulated PTU that are available during Phase 3 (end of flowering to physiological maturity) would be the most limiting growth phase for canola production throughout the Province. So if flowering is complete on average by the end of August in Region 2 and in mid-September in Region 1, and increasing temperature- and/or decreasing soil water availability-induced physiological maturity occurs 30 days later in each of those regions then one would expect below optimum canola production because of low levels of accumulated PTU. However, since for most RHFAs, there are sufficient PTU for Phase 1 and excess PTUs available for Phase 2 the flowering process may well be completed before the end of the 45 day period that we assumed necessary for completion of flowering. For example 6184 PTU are available for Phase 2 in RHFA 73 (Riversdal Ruens). If flowering is predicted to be completed after 3465 PTU this implies that 6184-3465 PTU or 2719 PTU could be added to the post flowering to physiological maturity growth stage (Phase 3), that would give a total of 7863 PTU for Phase 3 which is more than the predicted required PTU for the plants to achieve physiological maturity.

Total seasonal PTU

The predicted accumulated PTU required from planting to physiological maturity is 22427 °Cd.hr. Inspection of Tables 7 and 8 shows that all of the traditional grain producing RHFAs in Regions 1 and 2 receive more than 22324 indicating that, on average, **accumulated PTU from planting to physiological maturity should not be a limiting factor in canola production in any of these grain producing RHFAs**. It should be remembered that the data presented in the Tables are average values implying that there will be areas in each RHFA with lower and higher values than the mean. In most cases however, the lowest values within a RHFA should also not be limiting to canola production.

Spatial presentation of these total seasonal PTU in Figure 13 clearly shows that most of the Western Cape, excluding the mountainous regions, has sufficient PTU for canola production. Note that the total seasonal PTU available in the coastal areas between Knysna and Mosselbay,

where most of the cultivated land is used for irrigated cash crop and pasture production, is greater than the predicted required total seasonal PTU for canola production (Figure 13).

Having established that sufficient PTU are available for canola production over almost all the identified rainfed cultivated areas, and for all cultivated land currently used in cash crop and pasture production systems, it is necessary to evaluate the canola production potential of these areas as affected by seasonal water supply

c. Seasonal water supply (SWS)

The estimation and GIS modelling of long-term average SWS as it relates to soil water availability for canola production has yielded useful results. Estimated SWS of each RHFA in each of Regions 1 and 2 is listed in increasing numerical order in Tables 9 and 10 respectively.

First, the data reveal those RHFAs in each Region where SWS is less than 0mm indicating that those RHFAs have zero potential for canola production. Second, the SWS in the traditional grain producing RHFAs of Region 1 range from relatively low SWS (59mm) in the Sandveld saai- en Veldweidingsgebied (RHFA 76) to over 200mm in the Gemege Boerderygebied (RHFA 27) (Table 9), whilst in Region 2 estimated SWS in the traditional grain producing RHFAs ranges from very low (17mm) in the Gouritzriviervallei (RHFA 30) to over 240mm in Villiersdorp/Vyeboom (RHFA 91) (Table 10). Third, the analyses has identified areas of cultivated land in RHFAs that do not form part of the current rainfed grain production farming systems that have a SWS equal to or greater than many of the traditional grain producing RHFAs. The RHFAs with a SWS-based potential for canola production include: Region 1 – Koue-Bokkeveld (RHFA 46), Warm-Bokkeveld (RHFA 92), Winterhoek (RHFA 93), Elgin/Grabouw (RHFA 25); and for Region 2 – Bo-Langkloof (RHFA 9), Langeberg saagebied (RHFA 50), Langkloof (RHFA 52), and the RHFAs in the higher rainfall coastal areas of Mosselbay to Knysna (RHFAs 8, 11, 20, 38, 68 and 95).

d. Estimating canola production potential in the Western Cape based from seasonal water supply (SWS)

The area (ha) of each RHFA where our modelled estimates of canola production potential was greater than 0kg/ha, is presented in Tables 11 and 12, and in Figure 14. As stated earlier in this report we used the French & Schultz (1984) model, as adapted by Robertson and Kirkegaard (2005), as a rough guideline for determining areas of “low”, “intermediate” and “high” canola production potential in the Western Cape. Data presented by Hoffmann (2011) provide an opportunity to assess the practical value of our modelled canola production potential estimates in defining low, intermediate and high production potential. In the Hoffmann study, expert-group opinion techniques were used to obtain a consensus value for expected canola production in “good”, “average” and “poor” production seasons in each of several production regions that were identified for the Swartland and the Southern Cape. A summary of the results is presented in Table 15.

Production regions were defined by Hoffmann (2011) as RHFAs but this was a different definition to the one used in our study resulting in each of the Hoffmann RHFAs incorporating one or more of the RHFAs as defined in our study. Table 15 therefore shows our estimates of the % area of RHFAs (or parts of RHFAs) – as defined in our study - that were included in the RHFAs as defined in the Hoffmann study - refer to Figures 16 and 17 that illustrate the RHFAs as described by Hoffmann for the Swartland and Southern Cape respectively. By multiplying the

estimated canola yield for each RHFA in our study by the % area of the RHFA that contributed to the Hoffmann-defined RHFA we calculated a weighted yield from our study that was comparable to the estimated yield given in the Hoffmann study.

The weighted SWS-based yield estimates for relevant RHFAs in our study are presented in Table 15. These estimates are based on long-term average rainfall data. Yield prediction using the modified French and Schultz model is therefore based on typical “bell-shaped” rainfall patterns showing increasing monthly rainfall from April to July/August followed by decreasing monthly rainfall into spring and early-summer - see for example, long-term monthly rainfall data for Langgewens and Tygerhoek presented by Lombard (2011). Estimated crop response in our study is therefore a function of a constant availability of soil water based on the rainfall patterns and would ignore the variable weather patterns that are experienced in the Western Cape. Such weather patterns commonly include dry, hot spells that may persist for three to four weeks at critical times and have a major influence on the development of the crop. Since the Hoffmann defined “good”, “average” and “poor” years incorporate variability in the timing, amount and distribution of rainfall, as well as temperature, our modelled crop production potential for each RHFA could not be realistically compared to the Hoffmann yield estimates. However, general trends of yield potential among production regions within Regions 1 and 2 were similar (Table 15). We therefore used the distribution of SWS data presented in Tables 9 and 10 in an attempt to identify areas of “low”, “intermediate” and “high” canola production potential in each of Regions 1 and 2.

Division of RHFAs into the “low”, “intermediate” and “high” production categories was done on the understanding that our yield estimates for RHFAs within the Middel Ruens and Heidelberg Vlakte, which had low predicted SWS (Tables 9 and 10), tended to underestimate the yields suggest by the Hoffmann consensus group (Table 15). Where higher SWS were predicted, our SWS-based yields were similar to or greater than the consensus group estimates for Koeberg/Wellington the Middel Swartland and Goue Ruens (Table 15). Our division of RHFAs into the different production categories was also based on experience of crop production potential in the previously identified cultivated areas of each RHFA used for rainfed crop and crop/pasture production areas of each Region.

Whilst the average SWS predicted across a RHFA may be negative the GIS modelling extracted all rainfed cultivated land within a RHFA where the predicted SWS was positive. This process allowed for smaller areas that may have some potential for canola production to be identified. Tables 11 and 12 have each been divided into the “low”, “intermediate” and “high” production categories and RHFAs that are located in the traditional cropping regions of the Swartland and Southern Cape are highlighted.

There is an inherent scale mismatch in the spatial detail of the coarse rainfall data, which is rasterised at pixels of approximately 1 km x 1 km. This is a consequence of the relatively sparsely distributed climate recording stations across the province and the scale of the source data (Schulze, 2008). The field boundary detail is comparatively highly accurate vector data, digitised from imagery at a 2.5 m resolution. The spatial analysis therefore was at the scale of the coarser of the two -the rainfall data, which can lead to some underestimation of area, particularly on the smaller RHFAs with high topographical gradients. Furthermore, although the

rainfall data does include an elevation component in its interpolation, because of its native coarse resolution it cannot be considered to accurately capture rainfall variation at the steep topographic gradients in some mountainous RHFA, where rainfall-topography interactions have substantial impact on precipitation.

The French & Schultz (1984) model as adapted by Robertson and Kirkegaard (2005) and applied in this study predicts that for yields > 0 kg/ha canola can be cultivated, in average rainfall seasons, on 526 472ha and 526 199ha in Regions 1 and 2 respectively (Tables 11 & 12) which suggests a maximum total area of approximately 1 052 672ha in the Western Cape Province as a whole. If the identified areas with low production potential are excluded then the SWS-based model outputs suggest that canola could be cultivated on 399 678ha and 475 108ha in Regions 1 and 2 respectively (Tables 11 & 12). A total area of 874 786ha could therefore be suited to canola production based on our modelled SWS-based yield estimates, and the assumption that the low yield estimated for the “intermediate production potential” (Table 12), that derived from low SWS values, grossly under-estimated yield potential.

The modelled SWS-based estimates of areas suited to canola production were greater than the areas of land suited to cash-crop production indicated from the PICES and TPS estimates. In addition, factors other than SWS (such as soils) will obviously influence the suitability of land for canola production. We therefore consulted with experienced field-crops advisors in the Swartland and Southern Cape regions to include local knowledge on the effects of soils and climate on canola production potential within the areas of rainfed cultivated land that had a canola production > 0 kg/ha in each RHFA (Tables 11 and 12).

- e. Integrating local experience and the modelled effects of environmental factors on canola growth and development towards identification of areas suited to canola production in the Western Cape

The advisors were asked to assess our SWS-based estimates of the area of each RHFA where canola production was >0 kg/ha (Tables 11 and 12). On the basis of their knowledge and experience of the soils and climate of each RHFA, they were asked to estimate the proportion (%) the modelled area of cultivated land in each RHFA that would be suited to canola production. Subsequently, each RHFA was allocated to one of three categories in each of Regions 1 and 2. These categories were: the traditional grain producing areas, marginal and “new” production areas, and miscellaneous production areas with low- and/or high risk production potential. The results are presented in Tables 16 (Region 1) and 17 (Region 2) and include summarised comments from the advisory group.

Region 1 (mainly the Swartland sub-region)

- i. Traditional grain producing areas (Table 16a)

Together with the advisory group we estimate that approximately 350 000ha located in the traditional grain producing areas are suited to canola production. Of this area approximately 50 300ha has low production potential (RHFA 45 – Koringberg/Rooikaroo) and about 140 000ha has an intermediate production potential (RHFA 56 – Middel Swartland). The remainder of the RHFAs in this traditional grain producing area have high production potential on about 159 700ha.

ii. Marginal and “new” production areas (Table 16b)

Despite their extremely low canola production potential RHFAs 31 and 76 have been included in the marginal category as there are areas totalling about 2 000ha where it is estimated that canola could be produced economically. These areas are located mainly in patches on the eastern boundaries of these RHFAs (Figure 14).

Rainfed cultivated lands in RHFA 7 (Bergrivier/Paarl) and RHFA 90 (Vier-en-Twintig Riviere) are used mainly for cash crop and pasture/fodder production. However, the total area available for canola production is relatively small (about 1 400ha). As fields are also small and located in traditional irrigated fruit producing areas canola production potential is considered marginal.

Relatively large areas of cultivated lands (totalling about 11 000ha) appear to have potential for canola production in RHFAs 46 and 92 – the Koue- and Warm Bokkeveld respectively (Table 16b). However, while the modelled seasonal water supply (SWS) would suggest that these (newly identified) RHFAs have a high production potential, canola production is likely to be constrained by low availability of PTU and the potential for frost damage during flowering.

iii. Miscellaneous production areas (Table 16c)

Adjusted areas where canola production is estimated to be >0 kg/ha for the eleven RHFAs in this category total about 6 400ha. Most of these RHFAs lie outside of the traditional grain producing areas. Approximately 5 500ha (RHFAs 65 to 18 in Table 16c) are considered to be high risk canola production areas including RHFAs with relatively high SWS (e.g. RHFAs 67 and 18) due to poor water holding capacity of the sandy soils. The remaining cultivated areas (approximately 1 000ha) in RHFAs in this miscellaneous category are estimated to have relatively high canola production potential (but due to their location and the small fields canola production is considered to be impractical).

Region 2 (mainly the Southern Cape sub-region)

i. Traditional grain producing areas (Table 17a)

Together with the advisory group we estimate that approximately 390 000ha located in the traditional grain producing areas are suited to canola production. Of this area approximately 278 500ha has intermediate production potential (RHFAs 55 – Malgas/Heidelbergvlakte - to 73 –Riversdale Ruens). The remainder of the RHFAs in this traditional grain producing area have high production potential on about 111 000ha (RHFAs 74 – Riviersonderendvallei - to 16 –Caledon Ruens).

ii. Marginal and “new” production areas (Table 17b)

RHFAs 29, 42, 8, 68, 80, 12 and 91 are located within traditional grain producing areas of the southern Cape. These RHFAs were included in this marginal category due to either the relatively small area of cultivated land available for canola production and/or low canola production potential due to low SWS and/or sandy soils with low water holding capacity (Table 17b). Approximately 7 700ha in the Gouritz-Rooiruens and Kleinberg/Suurrug RHFAs have low potential whilst the remaining RHFAs in these traditional grain producing areas have moderate to high canola production potential. Soils are a major factor that potentially

can negatively affect rainfed cash-crop production in these RHFA (see comments in Table 17b).

Two “new” RHFA are included in this category with a total of approximately 7 600ha estimated to have canola production potential viz. Bo-Langkloof (RHFA 9) and Outeniqua/ Woodville/ Uplands (RHFA 68). Soils of RHFA 68 are problematic in that they are highly erodible duplex soils with a high fine fraction, low pH, and have P and trace element deficiencies. The Bo-Langkloof RHFA is located on the northern side of the Outeniqua range, has marginal SWS and the risk of frost damage during flowering, soils also tend to have low pH. Both these newly identified areas are therefore considered to be marginal with relatively high risk of poor canola production.

iii. Miscellaneous production areas (Table 17c)

RHFA 30 and 22 are located within traditional grain producing areas of the southern Cape but were included in this miscellaneous category due to the relatively small areas of cultivated land available for canola and low production potential due to low SWS and sandy soils.

Canola production potential for the remaining RHFA in this category range from intermediated to high (Table 17c). However, due to the location of many of these RHFA and the relatively small areas of cultivated lands within each RHFA canola production in these RHFA is considered impractical. Furthermore, in the case of RHFA 44 and 52, low availability of PTU as well as the risk of frost, and, in RHFA 95, poor soil characteristics, these RHFA are considered to have high risk for canola production.

General discussion and conclusions

Cultivated areas

The objective of this study was to determine the total area of rainfed arable land suited to canola production, and to develop tables and maps showing canola production regions in the Western Cape Province. Data sets from the DAWC and PICES provided baseline data on the areas of land allocated to rainfed crop and crop pasture production systems, averaged over the past ten years, for all Relatively Homogeneous Farming Areas (RHFA) in the Province. Evaluation of these data resulted in an estimate that approximately 782 000ha of arable land in the Western Cape would be suited to rainfed winter cereal crop production systems.

Growing degree days

The potential effects of environmental variables that influence the growth and development of canola were quantified using a GIS modelling framework for each RHFA. With few exceptions there were sufficient accumulated growing degree days (GDD) for medium maturity type conventional canola cultivars to achieve 50% flowering within 90 days from planting in all rainfed cultivated areas suited to winter cereal crop production systems in the Western Cape. This result is based on a planting date of 1 May in Region 1 and 15 April in Region 2.

Photothermal units

Accumulated photothermal units (PTU) for each of three growth phases identified for canola i.e. Phase 1 – planting to 50% flowering; Phase 2 – flowering; Phase 3 – post flowering to physiological maturity, were quantified for medium maturity type conventional canola cultivars in each RHFA. The

results indicated that almost all of the cultivated lands used for rainfed winter cereal crop production systems received sufficient PTU for Phases 1 and 2 but that insufficient PTU were available for canola plants to complete their physiological development to achieve optimum production during Phase 3 – a 30-day period in our model. However, under ideal temperature and soil water availability conditions during Phases 1 & 2, the end of flowering stage is likely to be completed in a shorter time frame than the 45 days allocated to flowering in our modelling of the physiological development of the canola plant. Under such conditions there should be sufficient PTU to allow canola to achieve normal (non-stressed) physiological maturity during Phase 3 in most RHFAs.

These observations on accumulated PTU are based on average long-term temperature data. However, most grain producing regions of the Western Cape experience extended periods of dry, hot weather during the growing season. Often these extended dry, hot periods occur during Phase 1 (in May) and/or in August/September (late Phase 2 and early Phase 3). Therefore, whilst there are sufficient PTU available, the potential physiological development of canola could be often be limited by excessive temperatures and/or by available soil water which, in turn, tend to extend the number of days required for each growth phase. In addition, the physiological development of the canola plant is often limited towards the end of Phase 3 through temperature- and/or water- stress induced physiological maturity thus limiting the potential of the plant to utilize available PTU.

In general, however, our modelled results indicate that, on their own, accumulated GGD and PTU are not limiting factors to the growth and development of canola in the rainfed crop a pasture production areas of most RHFAs in the Western Cape

Seasonal water supply

Seasonal water supply (SWS) is recognised as the main environmental factor influencing canola production. Predicted canola production, which was based on a SWS x WUE model, in the present study did not provide, in comparison with known long-term potential yields, realistic estimates of canola yield potential across all RHFAs. However, the range in predicted yields from “low”, through “intermediate” to “high” production potential provided a useful guideline towards allocating the RHFAs into “low”, “intermediate” and “high” canola production potential categories. The total area that was estimated to be suited to canola production based on SWS-yield predictions was about 875 000ha which is greater than the area of cultivated land suited to cereal grain production systems suggested from the TPS and PICES data sets.

The one major environmental variable that has a major influence on the production potential of all crops that was not taken into account in our model was the soil. This was due to the fact that sufficiently detailed regional soil classification data were not available for the purposes of this study. We therefore relied on the inputs of experienced field-crop advisors from the grain producing regions to assist in verifying, and adjusting where necessary, the area of each RHFA suited to canola production that resulted from the SWS-based yield predictions.

Identified areas suited to canola production in the Western Cape

Integration of local experience with the modelled effects of environmental factors on canola growth and development yielded the final outcomes of our efforts towards identifying areas suited to canola production in the Western Cape (Table 18).

Table 18. Areas (ha) suited to canola production within each of Regions 1 and 2 allocated to high , intermediate and low production categories for a) traditional grain production areas, b) “new” and marginal production areas and c) miscellaneous production areas

a)	Production potential		
Traditional grain areas	High	Intermediate	Low
Region 1 (ha)	161877	141683	50301
Region 2 (ha)	111175	278470	
Total (ha)	273052	420153	50301

b)	Production potential		
"New" and marginal areas	High	Intermediate	Low
Region 1 (ha)	12598		2000
Region 2 (ha)	8148	9037	11005
Total (ha)	20746	9037	13005

c)	Production potential		
Miscellaneous areas	High	Intermediate	Low
Region 1 (ha)	932	2028	3455
Region 2 (ha)	2334	3037	586
Total (ha)	3266	5065	4041

	Grand totals (ha)
Traditional grain areas =	743 506
“New” and marginal areas =	42 788
Miscellaneous areas =	12 372

The total area of cultivated land suited to rainfed canola production in the traditional winter cereal production sub-Regions of the Swartland and the Southern Cape is estimated at 743 500ha. Figure 15 clearly shows that canola has been planted throughout the traditional crop and crop/pasture production areas of the Swartland and Southern Cape sub-Regions thus supporting our estimates of the areas suited to canola production in these traditional grain production regions. We estimate that thirty seven per cent of this area (273 000ha) has high production potential, 56% (42 000ha) has intermediate production potential, and 7% (50 300ha) has low production potential. Division of the RHFAs into the low, intermediate and high production potential categories is debateable. This is particularly so for the RHFAs located in Region 2 due to the gross underestimation of actual long-term yields by the SWS-yield prediction of our modelling efforts. The Hoffmann expert consensus data provided some guidance but more area-based, field-scale yield data would be required to improve allocation of RHFAs (or portions of RHFAs) into the production categories.

“New” production areas with intermediate to high production potential totalling approximately 19 000ha have been identified whilst “marginal” production areas that include areas of low, intermediate and high production potential total approximately 24 000ha (Tables 16b, 17b & 18 – and refer to discussion in the text).

Areas allocated to the miscellaneous production areas total about 12 000ha and are included in this category due to the small size of lands, poor soils and high risk associated with canola production.

We recommend that canola production should be promoted on the estimated 743 500ha of traditional crop and crop/pasture production areas summarised in Table 18 with detailed estimated areas for each of the relevant RHFAs in Tables 16a and 17a. We further recommend that additional detailed investigation of the occurrence, timing and duration of frost during the growing season, and/or the physical and chemical suitability of soils in the many RHFAs listed in the “new” and marginal areas (Tables 16b & 17b) as well as in the “miscellaneous” areas (Tables 16c & 17c) is required before canola production could be promoted in these RHFAs.

Appendix 1

Literature review

Environmental factors that influence the growth, development and production of canola

As for all plants the growth and development of canola is affected by factors such as day-length, temperature, available soil moisture and soils.

Day-length and temperature

Phenological development in *Brassica* species is influenced primarily by photoperiod (day-length), temperature and vernalization. Whilst spring type canola does not require vernalisation to initiate the reproductive phase, vernalization does reduce “time-to-flowering” thus potentially shortening the time required to physiological maturity at seed ripening. However, it is mainly variations in latitude and planting date that expose canola plants to a wide range in photothermal (day-length x temperature) regimes that influence rate of crop development and, therefore, flowering and maturity date.

Kirkegaard et al (2012) describe the influence of day-length on the physiological development of canola as follows: “Canola is a qualitative day-length species (Major 1980) requiring 16 to 18h of daylength for minimum optimum photoperiod (MOP) and the initiation of reproduction. Daylength less than MOP results in the extension of the basic vegetative period (BVP) and a delay in flowering. Reproductive development is initiated at daylengths exceeding 10-12h.” In their study Kirkegaard et al (2012) show that the climate and daylength conditions in Australia resulted in a growing season that was twice as long as in Canada. This is due to the fact that, in Canada, spring canola emerges into an environment of increasing photoperiod, receiving almost immediately the amount of daylength required to initiate floral development, so that phenological development is largely driven by temperature. In Australia, as in the Western Cape Province of South Africa, canola (planted in autumn) emerges into an environment of decreasing photoperiod and grows for an extended period under short-days resulting in a much longer BVP than occurs in Canada. Daylength and temperature therefore interact in their influence on the physiological development of canola in the Western Cape.

Thermal time (or growing degree days – GDD) has commonly been used to predict the vegetative development of canola. GDD is defined as the accumulation of daily mean temperature above a base temperature of 0°C from seeding to 50% flowering (Canola Council of Canada 2003, and others, cited by Lombard 2011). Note that 50% flowering is defined as the stage at which 50% of the plants in a stand have first flower visible (Burton et.al. 2008). However, for the climatic conditions similar to those under which canola is produced in the Western Cape, Australian researchers such as Burton et al (2008) and Kirkegaard et al (2012) have found improved predictions of the physiological development of spring canola when combining GDD and day-length, expressed as photo-thermal units (PTU = $H_i \times GGD$).

Thermal time (GDD) is calculated as follows:

$$GDD = \sum T_{\text{mean}i} - T_{\text{base}},$$

where $T_{\text{mean}i}$ = mean daily temperature calculated as $(T_{\text{min}}+T_{\text{max}})/2$, and

$T_{base} = 0^{\circ}\text{C}$

Day-length (H_i) is calculated as:

Day light hours (daily) – sun rise to sun set.

Kirkegaard et al 2012 reported a highly significant relation between PTU and per cent development to physiological maturity (PDPM - calculated from total time in days to maturity) of the canola plant across several sites and seasons, following Morrison et al (1989). Specific growth stages chosen represented key physiological stages throughout the development of the plant. These stages were: HB1.0 (emergence), HB2.1 (start of the vegetative stage), HB2.4 (late vegetative stage), HB3.1 (start of bolting stage), HB4.1 (start of flowering stage), HB5.1 (start of ripening stage), and HB5.3 (physiological maturity) (Harper and Berkenkamp 1975). The relation is expressed as follows:

$$\text{PTU} = -526 + 231 \text{ PDPM} (r^2 = 0.97),$$

implying, for example, that approximately 12000 PTU would have been required if flowering were to commence when the plants had reached (in days) 55% of physiological maturity.

Rainfall

Being small-seeded, canola seed is poorly adapted to germinate and develop in sandy soils and in soils where seed/soil contact is poor, particularly in low rainfall conditions. The larger-seeds of cereal grains are better adapted to survive and develop under such conditions. In-season rainfall (April to October in excess of 300mm is required to achieve canola yields in excess of 2000 kg/ha (Anon. canola manual). However, due to the relatively low in-season rainfall and the large variations in the amount and timing of rains in the grain producing regions of the Western Cape, yields in excess of 2000 kg/ha are not commonly achieved. Risk associated with rainfall in the region and their effects on canola production need to be quantified. Burton et al (2008, citing Robertson et al 2002) state that in Australia canola has not performed consistently well in lower rainfall environments.

Plant available water at sowing and in-season (April to October) rainfall, have been shown to be major factors affecting canola production in the winter rainfall region of Australia (Farré et al 2007). These researchers identified three rainfall zones in Western Australia considering April to October rainfall and assessed (applying detailed simulation modelling using APSIM) the risk of producing canola as a function of sowing date and soil type in each of these zones. A summary of their findings follows:

High rainfall zone: long-term (April to October) average rainfall = 446mm

- In-season rainfall was usually sufficient to meet the environmental potential for canola production.
- Median yield estimated at 2000 to 3000 kg/ha depending on soil type.
- >80% chance of canola being profitable at break-even crop yields of 500, 1000 and 1300kg/ha (as a function of input costs and price).
- Due to high rainfall later sowing did not have as high a yield penalty as in the medium and low rainfall zones.
- Water-logging could be a problem on duplex soils in this high rainfall zone.

Medium rainfall zone: long-term (April to October) average rainfall = 264mm

- Median yield estimated at 1000 to 1500 kg/ha depending on soil type.

- >70%, >50% and >40% chance of canola being profitable at break-even crop yields of 500, 1000 and 1300kg/ha respectively (as a function of input costs and price).
- Late sowing has a greater negative effect on yield than the high rainfall zone.
- Appropriate agronomic strategies must be implemented to minimise negative impact of the relatively low and variable in-season rainfall

Low rainfall zone: long-term (April to October) average rainfall = 234mm

- Median yield estimated at 500 to 800 kg/ha depending on soil type.
- >50%, >30% and >10% chance of canola being profitable at break-even crop yields of 500, 1000 and 1300kg/ha respectively (as a function of input costs and price). Viability of canola production in these areas is highly sensitive to costs and prices.
- Late sowing has a similar negative effect on yield to the medium rainfall zone.
- Appropriate risk minimization and agronomic strategies must be implemented to minimise negative impact of the low and variable in-season rainfall

Following points should be considered in deciding on risk minimization strategies for canola production in the medium and low rainfall zones (Farré et al 2007):

- Availability of stored water an important consideration. 20mm of stored water has potential to increase yields by 200 kg/ha but additional stored water does not contribute significantly to final yield.
- Duplex soils have greater potential for storing water.
- Ensure good summer stubble cover and weed free fallow.
- Plant as early as possible.
- Use of short-season cultivars

Other, less detailed, methods have been used to relate canola yields to rainfall. Hocking et al (1997 – cited by Robertson and Kirkegaard 2005) plotted yield of canola against water use, where water use was calculated as rainfall during crop growth plus water depletion as measured in soil cores. This resulted in a water-use efficiency (WUE) of 12.5 kg/ha.mm at rainfall in excess of 110mm. Other research results and long-term simulations showed that there was considerable variability in WUE (from 3 to 18 kg/ha.mm) and suggested an upper limit of about 13 kg/ha.mm (Cocks et al 2001 - cited by Robertson and Kirkegaard 2005). Thomas (2012) observed that local yields suggested a WUE of 6.4 kg/ha.mm (160 kg/ha per 25mm) and that with good agronomic practices WUE should improve to 11.2 kg/ha.mm (280kg/ha per 25mm)

In a study on water-use efficiency (WUE) of dryland canola in an equi-seasonal rainfall environment (similar to parts of the southern Cape) Robertson and Kirkegaard (2005) developed a relation between seasonal water supply and grain yield where:

$$\text{Grain yield (kg/ha)} = 10.6 \times \text{seasonal water supply} - 1243 \quad (R^2 = 68).$$

Seasonal water supply was calculated as: in-crop rainfall + starting available water – finishing available soil water.

The range in slope was from 8 to 15 kg/ha.mm

The intercept on the seasonal water supply axis (indicating zero grain yield below this intercept) was 120 mm which is similar to estimated minimum in-season rainfall suggested by Hocking et al (1997).

Where in-crop rainfall is < 450:

seasonal water supply = [in-crop rain + soil water at sowing] – [soil water at harvest] – 120, AND

soil water at sowing = (fallow season rainfall – 80) x 0.5 (where 0.5 ranges from 0.4 to 0.6 depending on timing and amount of fallow rain)

soil water at harvest = (post flowering rainfall – 50) x 0.5 (where 0.5 ranges from 0.5 to 1.0 in wetter locations and from 0.2 to 0.5 in drier locations)

Robertson and Kirkegaard (2005) made the following observations that are relevant to the current study.

- Long-term simulations show median slopes 12 and 11 kg/ha.mm for conventional and TT cultivars respectively.
- WUE of 14 to 15 kg/ha.mm are possible in areas where water used most efficiently due to its timing in relation to crop demand and minimal unproductive losses occur.
- WUE of 8 to 9 kg/ha.mm in seasons where water is used less efficiently due to poorer timing of rainfall in relation to crop demand and increased unproductive water loss.
- Later sowing results in reduced water use efficiency. WUE reduced by 10% for each month's delay in sowing between early April and early July.
- Simulated soil evaporation mean values of 157mm suggesting that intercepts on the water supply axis of 120mm and 150 for conventional and TT cultivars are not unreasonable.
- Canola yield not limited by seasonal water supply >450 mm.
- Fallow (cover intact and no weeds) leads to 40 to 60% of summer rains being stored above threshold of 80 mm (remember their study was done for an equi-seasonal rainfall zone).

Various authors including Robertson and Kirkegaard (2005) and Bowman & Scott (2009) have presented modifications to what is referred to as the French & Schultz (1984) approach to calculate potential yield from potential water use. Water use efficiency (WUE) is calculated as:

$WUE = \text{grain yield per ha} / SWS$

where

SWS = seasonal water supply as calculated above

This equation can then be written as:

Grain yield = WUE x SWS

a WUE applicable to canola is then applied in the equation

Soils

Canola prefers well-drained soil with a high potential for wheat production (Anon. canola manual). However, the fact that canola is grown over a wide range of environments (and latitudes) in Australia and, to a lesser extent in the Western Cape, suggests that it is adapted to a wide range in

soil types (Burton et al 2008; Potter et al 1999, Anon. canola manual) – “soils that grow the best wheat also grow the best canola” (Potter et al 1999). Light sandy soils should preferably be avoided as should soils that tend to crust or that are subject to wind erosion (Anon. canola manual). Canola performs best at soil pH (KCl) in the range 5 to 7 with an acid saturation of < 10%. Due to its tap-root system canola roots can penetrate to depths > 1000 mm.

Soils of the two main grain-producing regions in the Western Cape Province (the Swartland and the southern Cape) range from shallow clay-loams (10–20 per cent clay) derived from shale, to well-drained sands (SIRI 1987). The average depth (topsoil plus sub-soil) of the relatively fertile shale-derived soils varies from 200 to 400 mm, but many of these soils have a stone fraction of more than 30 per cent. Low soil volume limits crop production on these shale-derived soils but, in some areas, the shale layers tend to be off-horizontal, allowing roots to penetrate between layers of unconsolidated rock. The shale derived soils have a higher potential for canola (and other cereal crops) production than the sandy soil of these two grain producing regions.

Aeolian calcareous, sandy soils are found in the western and southern coastal areas. These soils are deeper than the shale-derived soils (>750 mm) but have low clay content (less than 5 per cent clay), resulting in low water-holding capacity and thus low crop production potential.

The lower proportion of winter rainfall in the southern Cape together with low soil volume potentially results in a lower soil moisture availability in the growing season than in the Swartland leading to inherently higher risks with winter crop production. However, summer rainfall and milder climatic conditions result in a more rapid breakdown of crop residues that are then more readily incorporated into the soils of the southern Cape than is the case in the Swartland. Typically, soil organic carbon in the shale derived soils of the southern Cape tends to be above 1.5 percent compared to 1.0 percent and lower in the shale derived soils of the Swartland.

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