Using Seasonal Rainfall with APSIM to Improve Maize Production in the Modder River Catchment

by

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TABLE OF CONTENTS

DECLARATION

I declare that the dissertation hereby submitted for the degree of Magister Scientiae Agriculturae in Agricultural Meteorology at the University of the Free State is my own independent work and has not previously been submitted by me at another university or faculty. I further more cede copyright of this dissertation in favour of the University of the Free State.

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ABSTRACT

In order to meet the food requirements of an ever-growing population, agricultural production needs to increase. This is especially true for maize production in South Africa as it is the staple food for a large portion of the rural indigenous population. Climate variability is one of the major causes of volatility in agricultural production and causes uncertainty for maize production at the subsistence level. Small-scale farmers within the Modder River Catchment have a poor quantative understanding of seasonal rainfall and their relationship to their management strategies. In countries prone to high seasonal climatic variability, crop growth models such as APSIM can be used to assist farmers in making decisions regarding the suitability of different management strategies. This means that climate forecasts could be translated into crop production, while alternative management practices would be associated with different economic outcomes. The opportunity arose to aid these farmers by optimising rainfed maize production. Subsequently, the objective of this study was to produce an advisory for small-scale rainfed maize farmers in the Modder River Catchment.

Historical rainfall data (1950-1999) from selected rainfed maize production areas within the Modder River Catchment were used to calculate the seasonal rainfall totals for October to December (OND) and January to March (JFM). During dry seasons, the expected rainfall totals was less than 101.0 and 147.5 mm for OND and JFM, respectively. During wet seasons, the expected rainfall totals was more than 204.0 and 267.5 mm for OND and JFM, respectively. Recommended management practices were employed to validate APSIM using observed environmental and maize yield data for the 1980/81 to 2004/2005 seasons in the vicinity of Bloemfontein. Maize yields were simulated using two medium growth period cultivars (PAN 6479 and Pioneer 3237) under different planting dates, plant population densities, fertiliser applications and weeding frequencies. The model simulated PAN 6479 better than Pioneer 3237. For Pan 6479, the best set of management practices corresponded to a R^2 of 0.66, D-index of 0.89, modelling efficiency of 0.59 and RMSEu/RMSE of 0.88. For Pioneer 3237, the modelling efficiency values under different management practices were negative.

Stepwise linear regression was used to select those yield predictors that adhered to a partial R^2 value greater than 0.0001 at a significance level of 0.15. In general it's usually better to plant early (November) regardless of the seasonal rainfall scenarios. Advisories were set up to convey information regarding the best, second best and worst set of management practices under each seasonal rainfall scenario. These advisories also include the related field costs along with potential yields and economic benefits at the 25, 50 and 75% probability levels for each set of management practices. For example, during AN-AN rainfall conditions, the best set of management practices involved planting during 16-30 November and 1-15 November, weeding twice, 50 and 75 kg ha^{-1} N and using 21 000 and 18 000 plants ha^{-1} for PAN 6479 and Pioneer 3237, respectively. Farmers would spend R1 798 ha^{-1} on field costs when planting PAN 6479, while obtaining a yield of 2 854 kg ha^{-1} and making a profit of R1 972 ha^{-1} at the 50% probability level. For Pioneer 3237 the field costs would amount to R2 338 ha^{-1}, while realising a yield of 4 232 kg ha^{-1} resulting in a profit of R3 253 ha^{-1} at the same probability level. The recommended management practices under various seasonal rainfall scenarios could assist small-scale rainfed maize farmers to increase their yields and maximise the associated profit. Unfortunately, site-specific calibration of APSIM is required against observed sets of climate, soil and yield data for which the associated management practices are known before these advisories can be used by extension officers to advise small-scale farmers within the Modder River catchment.

Key words: *Climate variability, crop growth model, economic analysis, recommended management practices, small-scale farmers*

OPSOMMING

Landbouproduksie sal moet toeneem om in die voedselbehoeftes van ‘n steeds groeiende bevolking te voldoen. Dit is veral waar in die geval van mielieproduksie in Suid-Afrika aangesien dit die stapelvoedsel vir ‘n groot gedeelte van die landelike inheemse bevolking uitmaak. Klimaatveranderlikheid is een van die hoofoorsake van onstabiliteit in landbouproduksie en bedreig mielieproduksie op bestaansvlak. Kleinskaalse boere in die Modderrivier-opvanggebied weet nie altyd hoe om inligting rakende die seisoenale reënval in hul bestuurspraktyke te inkorporeer nie. In lande wat onder hoë seisoenale klimaatveranderlikheid gebuk gaan, kan gewasgroeimodelle soos APSIM gebruik word om boere te help om besluite te neem rakende die geskiktheid van verskillende bestuurstrategieë. Dit beteken dat klimaatvoorspellings gebruik kan word om gewasproduksie te skat, terwyl alternatiewe bestuurspraktyke met verskillende ekonomiese uitkomste geassosieer sal word. Die geleentheid het homself voorgedoen om hierdie boere by te staan deur droëland mielieproduksie te optimeer. Gevolglik was die doel van hierdie studie om ‘n advieshulpmiddel vir kleinskaalse droëland mielieboere in die Modderrivier-opvanggebied daar te stel.

Historiese reënvaldata (1950-1999) van gekose droëland mielieproduksie-areas binne die Modderrivier-opvanggebied is gebruik om die seisoenale reënvaltotale vir Oktober tot Desember (OND) en Januarie tot Maart (JFM) te bereken. Gedurende droë seisoene was die verwagte reënvaltotale respektiewelik minder as 101.0 en 147.5 mm vir OND en JFM. Gedurende nat seisoene was die verwagte reënvaltotale respektiewelik meer as 204.0 en 267.5 mm vir OND en JFM. Aanbevole bestuurspraktyke is aangewend om APSIM te verifieër aan die hand van waargenome omgewingsdata en mielie-opbrengsdata vir die 1980/81 tot 2004/2005 seisoene in die omgewing van Bloemfontein. Mielie-opbrengste is gesimuleer vir twee medium-groeier kultivars (PAN 6479 en Pioneer 3237), onder verskillende plantdatums, plantbevolkingsdigthede, kunsmistoedienings en onkruidbeheer-frekwensies. Die model het PAN 6479 beter as Pioneer 3237 gesimuleer. Vir Pan 6479 het die beste stel bestuurspraktyke ooreengestem met ‘n R^2 van 0.66, D-indeks van 0.89, modelleringseffektiwiteit van 0.59 en RMSEu/RMSE van 0.88.

Die modelleringseffektiwiteitswaardes vir Pioneer 3237 was negatief onder verskillende bestuurspraktyke.

Stapsgewyse lineêre regressie is gebruik om daardie opbrengsvoorspellers te kies wat voldoen het aan ‘n gedeeltelike R^2-waarde groter as 0.0001 by ‘n betekenisvlak van 0.15. In die algemeen is dit normaalweg beter om vroeër te plant (November) ongeag die seisoenale reënvalscenario. Advieshulmiddels is opgestel om inligting rakende die beste, tweede beste en slegste stel bestuurspraktyke onder elke seisoenale reënvalscenario weer te gee. Hierdie advieshulpmiddels sluit ook in die verwante veldkoste tesame met die potensiële opbrengste en ekonomiese voordele by die 25, 50 en 75% waarskynlikheidsvlakke vir elke stel bestuurspraktyke. Byvoorbeeld, gedurende bo-normale gevolg deur bo-normale reënvaltoestande het die beste stel bestuurspraktyke behels dat daar respektiewelik aangeplant word gedurende 16-30 November en 1-15 November, onkruidbeheer twee maal toegepas word, 50 en 75 kg ha^{-1} N toegedien word en 21 000 en 18 000 plante ha^{-1} gebruik word vir PAN 6479 en Pioneer 3237. Boere sal R1 798 ha^{-1} aan veldkostes spandeer wanneer hul PAN 6479 aanplant, terwyl hul ‘n opbrengs van 2 854 kg ha^{-1} kon inbring en ‘n wins van R1 972 ha^{-1} maak teen die 50% waarskynlikheidsvlak. Vir Pioneer 3237 sou die veldkoste sowat R2 338 ha^{-1} beloop teenoor ‘n opbrengs van 4 232 kg ha^{-1} wat sou lei tot ‘n wins van R3 253 ha^{-1} teen dieselfde waarskynlikheidsvlak. Die aanbevole bestuurspraktyke onder verskeie seisoenale reënvalscenario’s kan droëland mielieboere in staat stel om hul opbrengste te vergroot en die meegaande wins te maksimeer. Voordat hierdie advieshulpmiddels deur voorligtingsbeamptes gebruik kan word om kleinskaalse boere in die Modderrivier-opvanggebied te adviseer, word ʼn punt-spesifieke kalibrasie van APSIM teenoor waargenome stelle klimaat-, grond- en opbrengsdata benodig waarvoor die meegaande bestuurspraktyke bekend is.

Sleutelwoorde: *Aanbevole bestuurspraktyke, ekonomiese ontleding, gewasgroeimodel, kleinskaalse boere, klimaatveranderlikheid*

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LIST OF ABBREVIATIONS AND SYMBOLS

AMP	=	Annual amplitude in monthly temperature
AN	=	Above-Normal
AN-AN	=	Above-normal followed by above-normal
AN-BN	=	Above-normal followed by below-normal
AN-NN	=	Above-normal followed by near-normal
APSIM	=	Agricultural Production Systems Simulator
APSRU	=	Agricultural Production Systems Research Unit
BD	=	Bulk density
BN	=	Below-Normal
BN-AN	=	Below-normal followed by above-normal
BN-BN	=	Below-normal followed by below-normal
BN-NN	=	Below-normal followed by near-normal
Bv36	=	Bainsvlei ecotope
CDF	=	Cumulative Distribution Function
CPC	=	Climate Prediction Centre
CSIRO	=	Commonwealth Scientific Industrial Research Organisation
D	=	Index of agreement
DAFF	=	Department of Agriculture, Forestry and Fisheries
DUL	=	Drained Upper Limit
ECMWF	=	European Centre for Medium-Range Weather Forecasts
GCM	=	General Circulation Model
GIS	=	Geographical Information System
IRI	=	International Research Institute for Climate Prediction
JFM	=	January, February and March
kg ha^{-1}	=	Kilogram per hectare
LL	=	Crop Lower Limit
ME	=	Mean Error
N	=	Nitrogen
NH_4^+	=	Ammonium ion

NN	=	Near-Normal
NN-AN	=	Near-normal followed by Above-normal
NN-BN	=	Near-normal followed by below-normal
NN-NN	=	Near-normal followed by near-normal
NO_3^-	=	Nitrate ion
NOAA	=	National Oceanic and Atmospheric Administration
OC	=	Organic carbon
OND	=	October, November and December
PAWC	=	Plant Available Water Capacity
QC	=	Quaternary Catchment
R ha^{-1}	=	Rand per hectare
R^2	=	Coefficient of correlation
RMSE	=	Root Mean Square Error
RMSEs	=	systematic Root Mean Square Error
RMSEu	=	unsystematic Root Mean Square Error
SAS	=	Statistical Analytical Simulation
SAT	=	Saturation
SAWS	=	South African Weather Service
SOILN	=	Soil Nitrogen module
SOILP	=	Soil Phosphorus module
SST	=	Sea-Surface Temperature
Sw	=	Glen/Swartland-Rouxville ecotope
Sw31	=	Swartland ecotope
TAV	=	Annual average ambient temperature
UKMO	=	United Kingdom Meteorological Office
Va	=	Vlakspruit/Arcadia-Lonehill ecotope

CHAPTER 1 INTRODUCTION

1.1 Background

The world population, which stood at 6.8 billion in 2009, was projected to reach 7 billion in 2011 and 9 billion by 2050 (UN Population Division, 2009). In order to meet the food requirements of an increasing population and achieve food security, agricultural production would need to increase (Inocencio *et al*., 2003). Maize (*Zea mays L.*) is a staple food in South Africa, particularly under the rural indigenous population (Walker & Schulze, 2006). There is thus a need to improve smallholder rainfed maize production in a sustainable manner, since it is often typified by low yields which are often significantly lower than the land's potential (Walker & Schulze, 2006).

Climate variability is one of the major causes of volatility in agricultural production and causes uncertainty for maize production at the subsistence level (Dube & Jury, 2003). The uncertainty and often deficiency of seasonal rainfall often raise concerns in agricultural communities in regions where the economic future of crop production is threatened (McCown *et al*., 1996). Waddington (1993) confirmed this by stating that constraints in agricultural productivity in southern Africa was caused by climate variability, which strongly suggests that reducing the risk associated with climate variability will increase the potential for crop production in South Africa. On a seasonal scale, mismatches between crop water demand and rainfall amount resulting from dry or wet spells, could cause water stress in crops or excess drainage of water below the crop's root zone (Wang *et al.,* 2008).

The development of skilful extended-range weather and seasonal forecasting capabilities has a direct economic benefit in South Africa due to their value in agricultural production (Palmer & Anderson, 1994; Barnston *et al.*, 1996). The value of a seasonal forecast will depend on its accuracy and the management options available to farmers, so that they may take advantage of the forecasts (Nicholls, 1991; 2000 cited in Stone & Meinke, 2005). Mishra *et al.* (2008) illustrated that the potential benefit from incorporating seasonal forecasts into agronomic management practices was expected to be the greatest early in the growing season.

Understanding surface-atmosphere interactions and progress in global climate modelling combined with investments in monitoring the tropical oceans resulted in improved predictability of climate fluctuations months in advance (Stone & Meinke, 2005). Operational seasonal rainfall forecasts, which have a spatial resolution similar to the grid spacing of the climate prediction models and is averaged in time over 3-month seasons, are typically expressed as rainfall anomalies or tercile probabilities (Hansen & Indeje, 2004). Gong *et al*. (2003) listed several institutions that issue seasonal climate forecast. These include the South African Weather Service (SAWS), European Centre for Medium-Range Weather Forecasts (ECMWF), National Oceanic and Atmospheric Administration (NOAA), Climate Prediction Centre (CPC), United Kingdom Meteorological Office (UKMO), and the International Research Institute for Climate Prediction (IRI) to name but a few.

Seasonal climate forecasts are being used increasingly to benefit decision making in the more climate-sensitive sectors of the economy (White, 2000). Hansen and Indeje (2004) identified two problems that farmers are facing when using seasonal climate forecasts to improve management practices. Firstly, the climate forecasts should be translated into crop production. Secondly, the economic outcomes of the management practices should be incorporated under climate forecasts. Seasonal forecasts have to deal with a need that is real and perceived by farmers such as the benefits of seasonal forecasts on decision making that is compatible with their goals (Hansen, 2002).

Season to season variability in production and long-term trends in production require the use of crop growth models (McCown *et al.,* 1996). There is growing interest in linking seasonal forecasts with crop growth models to improve predictability of crop response (Hansen *et al.,* 2004). During this 21st century, crop modelling should be a priority to develop sustainable agricultural systems (Sivakumar, 2000; cited in Stone & Meinke, 2005). For the range of management practices, the key objective of crop growth models is to simulate agricultural production under different climate and soil conditions (Radha Krishna Murthy, 2004). A crop growth model offers the advantage of analysing cropping systems and their alternative management options experimentally (Stone & Meinke, 2005). These crop simulation models take account of climate variability to assess risks involving alternative management practices (Uehara & Tsuji, 1998 cited in Abraha & Savage, 2006). Locally tested crop simulation models like the Agricultural Production Systems Simulator Model (APSIM) could explore the production outcomes of a large range of management alternatives under a range of climatic conditions (Hammer *et al.,* 1996; Meinke *et al.,* 1996; Carberry *et al.,* 2000; Royce *et al.,* 2001).

Keating and Meinke (1998) indicated that in regions with high seasonal climatic variability (Africa, Australia, south-east Asia and South America), model simulations could provide information about different management options to assist farmers in decision making. Combining seasonal climate forecasts and model simulations to evaluate management practices could maximise the profitability of farm operations by reducing climatic risk considerably (Hammer *et al.,* 2001). Farmers can use the outputs of combined seasonal crop-climate forecasting information: (1) as a decision making tool; (2) for monitoring crop performance during critical stages; and (3) for potential improvements in their overall cropping systems. This may be through increased crop production and farm profitability or through reduction in risks associated with climate variability (Meinke & Stone (2005).

1.2 Objectives of the research

Smallholder farmers within the Modder River Catchment have a poor quantative understanding of seasonal rainfall and its relationship to their management strategies (Zuma-Netshiukhwi, 2010). This could be because (i) they do not typically measure rainfall; (ii) they have poor access to relevant information; and (iii) the information is presented in terms of rainfall outcomes, rather than yield expectations. The research question thus arises: “Is it possible to optimise rainfed maize production within the Modder River Catchment by using seasonal rainfall forecasts?”

The overall objective of this study was to produce an advisory for smallholder rainfed maize farmers in the Modder River Catchment. The aim of this advisory was to relay what set of management practices farmers should use under various seasonal rainfall conditions. In addition, the advisory also provided information regarding the potential profit/loss associated with these management practices.

The specific objectives of this study were:

a) To select rainfed maize production areas within the Modder River Catchment;
b) To obtain historical seasonal rainfall data for the selected areas;
c) To set up APSIM for the selected areas;
d) To validate APSIM against measured maize yields;
e) To simulate maize yields for the selected areas using APSIM;
f) To assess the comparative economic benefit of different management practices under various seasonal rainfall scenarios; and
g) To create an advisory for rainfed maize production based on various seasonal rainfall scenarios.

1.3 Organisation of the report

The literature review presented in Chapter 2, provides an overview of crop modelling and previous studies using APSIM in Africa. Various factors that influence maize production (e.g. climate, soil, planting date, plant population density, fertiliser application rate and weeding control) are then discussed, followed by a review of management practices for rainfed maize production in the Free State province.

In Chapter 3 the methodology of the research is discussed. This section describes the data that were used, how the crop growth model was set up, and what methods were used to analyse the simulated maize yields. This section also includes a description of how the advisories were developed.

Chapter 4 divulges the results of this research project which culminates in the various advisory flow charts. Concluding remarks are presented in Chapter 5.

CHAPTER 2 LITERATURE REVIEW

2.1 Background

Agricultural Production Systems Simulator (APSIM) is described as a software system which allows: (a) modules of crop and pasture production, residue decomposition, soil water and nutrient flow, and erosion to be readily re-constructed to simulate various production systems; and (b) soil and crop management to be dynamically simulated using conditional rules (McCown *et al*., 1996). Collaboration between two groups, the Commonwealth Scientific Industrial Research Organisation (CSIRO) and the Agricultural Production Systems Research Unit (APSRU), lead to the development of APSIM in 1991. The development team grew from the initial 2 programmers and 6 scientists to 6 programmers and software engineers and 12 scientists in 2003 (Keating *et al.,* 2003).

The initial motivation to develop APSIM stemmed from the need for modelling tools that offer accurate simulations of crop production in relation to climate, genotype, soil and management factors, by addressing long-term resource management factors in farming systems (Keating *et al.,* 2003). In order for the software to simulate crop production accurately, the following had to be met (McCown *et al*., 1996): (1) adequate sensitivity to extremes of environmental inputs to simulate yield variation for analysis of economic risks; (2) the ability to simulate trends in soil productivity and erosion as influenced by management, including crop sequencing, intercropping, and crop residue management; and (3) efficient development of the modelling system by research teams.

APSIM was developed to simulate biophysical processes in farming systems, in particular where there is interest in the economic and ecological outcomes of management practices in the face of climate risk (Keating *et al*., 2003). ASPIM presents a major investment by its improved simulation in agricultural system research in combining farming research methodology with operational research (McCown *et al.,* 1996).

The suitability of APSIM to predictive modelling is demonstrated by the following attributes: (1) the ability to simulate important phenomena due to improved representation of certain aspects of the cropping system; (2) advanced setup and ease in which routines from different modules can be combined; and (3) support teams which assist in improving and testing the various modules (McCown *et al*., 1996).

The modelling process

The modelling framework of APSIM is made up of different components such as biophysical modules, management modules, input and output data modules and a simulation engine (Keating *et al*., 2003). Biophysical modules simulate physical and biological processes in farming systems, while the management module allows users to choose the rules that control the behaviour of the simulation. The simulation engine's main function is to drive the simulation process and to pass messages from one module to another (Keating *et al*., 2003). The framework of APSIM is illustrated in Figure 2.1.

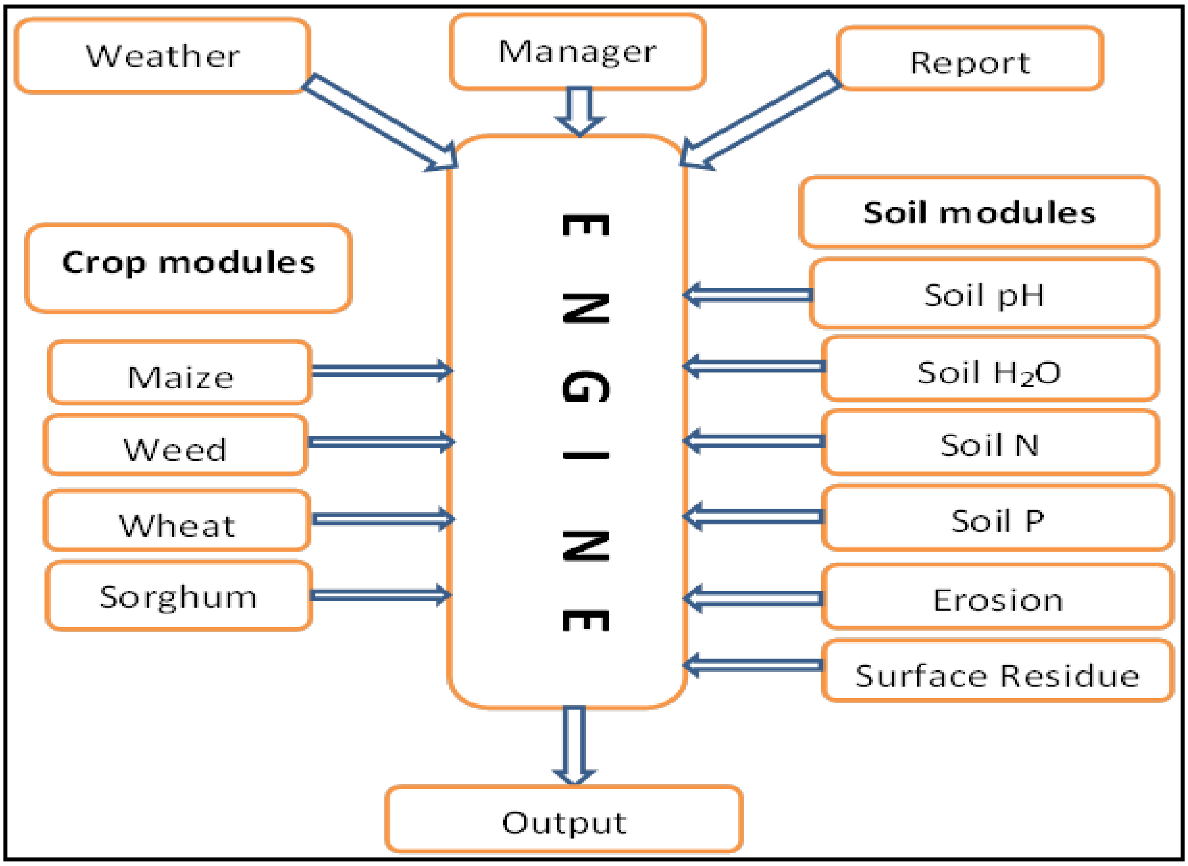

Figure 2.1: Structure of the APSIM program (adopted from McCown *et al*., 1996).

APSIM is a sensitive crop growth model; any slight changes to the existing code of modules could affect all functions inside the modules. Various high order processes such as crop production and soil water balance are represented as modules in Figure 2.1 that relate to one another by an engine; whereas more than one growth module can be connected simultaneously (McCown *et al*., 1996). APSIM modules typically require initialisation data and temporal data as the simulation proceeds. Initialisation data is usually categorised into generic data (which defines the module for all simulations) and simulation specific parameter data such as site, cultivar and management characteristics (McCown *et al*., 1996). Climate data are stored in a predefined format in the weather module. Modules for simulating growth, development and crop yields, pastures and forests and the interactions of these modules with soil are contained in APSIM. Keating *et al*. (2003) listed the crop modules that are currently available in APSIM. These are barley, canola, chickpea, cotton, cowpea, hemp, fababean, lupin, maize, millet, mucuna, mungbean, navybean, peanut, pigeonpea, sorghum, soya bean, sunflower, wheat and sugarcane. These crop mudules simulate the physiological process using weather data, soil characteristics and crop management practices on a daily time-step (Keating *et al*., 2003).

The maize module in APSIM was developed by combining two derivatives of the CERES-MAIZE modules, namely CM-KEN by Keating *et al*. (1991; 1992) and CM-SAT by Carberry *et al*. (1989) and Carberry & Abrecht (1991) of different maize cultivars. The maize module simulates maize growth on a daily time-step, while maize responds to climate, soil water supply and soil nitrogen. The phenology of maize in APSIM consists of eleven crop stages and nine phases (time between stages), with the commencement of each stage being determined by the accumulation of thermal time (except for sowing to germination which is driven by soil moisture). Each day the phenology routines calculate that day's thermal time (in degree days) from hourly air temperatures interpolated from the daily maximum and minimum temperatures.

As indicated in Figure 2.1, the soil modules contain soil nitrogen, soil phosphorus, soil water, soil pH, surface residues, and soil erosion. The soil nitrogen module (SOILN) was included to simulate the mineralisation of nitrogen and nitrogen supplies available to a crop from the soil, as well as residue from previous crops (Keating *et al*., 2003). Jones and Kiniry (1986) and Littleboy *et al*. (1992) used CERES and PERFECT models, respectively, to create a soil water module using a cascading water balance model. In the simulation process, the soil water module is interfaced with surface residues and crop modules. This allows the soil water balance to respond to changes in the crop cover and surface residue status via tillage, decomposition and crop growth (Keating *et al*., 2003). The maize module feeds information pertaining to the soil water and nitrogen intake to the soil water and soil nitrogen modules on a daily basis. Information on crop cover is used in the soil water module for calculation of evaporation rates and runoff. At harvesting of the crop, the stover and root residues are passed from the crop module to the residue and soil nitrogen modules, respectively (Keating *et al*., 2003). The soil phosphorus module (SoilP) simulates the available soil phosphorus, while crop modules use soil phosphorus to modify growth processes (Keating *et al*., 2003). The acidification of the soil and how soil pH changes through the soil profile is determined by the soil pH module. Hochman *et al*. (1998) calculated the balance of hydrogen ions in the soil-plant system and related it to changes in soil pH inside the soil pH module.

Rose (1985 cited in Keating *et al*., 2003) calculated the soil erosion by water using runoff volume from the soil water module, cover from residue and crop modules, and sediment concentration. The calculation consists of the daily average sediment concentration as a function of cover and user-defined parameters such as land slope and soil parameters. Freebairn and Wockner (1986) created the soil erosion equation used in the PERFECT model (Littleboy *et al*., 1992). The equation calculates daily average sediment concentration from a cover-concentration function and is modified using slope-length and erodibility. Thus, soil erodibility values are used as a starting point for estimating soil loss, but the model is not limited to calculating annual average soil loss and is linked to runoff rather than to rainfall erosivity (Keating *et al*., 2003). Development of the management module in APSIM came from the requirement to explicitly identify and address management functions (Keating *et al*., 2003). Its functions include resetting individual module values; reinitialising all data in modules to a given state; the sowing and harvesting of crops; the fertiliser application rate, weeding control and the tillage of soil; the calculation of additional variables to track the system state and the reporting thereof in response to events or conditional logic (McCown *et al*., 1996).

2.2 Previous studies using APSIM in Africa

Dimes and Du Toit (2009) used APSIM to simulate maize, groundnut and cowpea yields as well as their water balance in the Limpopo Province for the 2007/2008 cropping season. Field experiments were conducted at a smallholder farming village located in Tafelkop, Sekhukhune District. On-farm experimentation aimed to quantify the water use efficiency of maize, groundnut and cowpea crops. Plant biomass, grain yield and soil water balance of the crops were simulated by APSIM and the model outputs were compared to measured data. Measured crop yields, soil water and nutrient data were used to evaluate APSIM's performance in simulating water productivity and soil water balance for the crops.

APSIM simulated maize yields better than that of the two legumes, for which both grain and biomass yields were slightly under-simulated. The model indicated differences in crop water distribution within the root zone when simulating the soil water content over time. When the model outputs were used to fill gaps in the field measurement it indicated reduced water use efficiency for all three crops. The model also managed to capture the soil water distribution in the sample rooting layer for all crops. The overall performance of APSIM in simulating changes in soil water was reliable for maize, but not for cowpea and groundnut. Dimes and Du Toit (2009) found that APSIM's good performance in simulating the crop growth and yield, as well as the associated observed changes in the soil water content of the rooting zones encouraged the use of the model as a tool to quantify water productivity of crops in the Limpopo Province.

Whitbread *et al*. (2010) highlighted exercises wherein APSIM was used to simulate soil processes in response-constrained and low yielding maize/legume systems in southern Africa. APSIM was used: (a) to add value to field experimentation and demonstration; (b) to facilitate direct engagement with farmers; (c) to explore system constraints and opportunities with researchers and agents; and (d) to help create the information or systems which can be utilised by policy makers, banks, insurance institutions and service providers.

APSIM was also modified for southern African conditions by Ncube *et al.* (2007; 2009) in order to add value to field experimentation and demonstration to smallholder farms. This involved the interpretation of field experiments and incorporating seasonal variability and risk assessment. Major benefits were the development of an understanding of treatment response over a range of seasons and the development of extension guidelines. Kamanga (2002) used APSIM to simulate the response of maize to low N-fertiliser application rates, the potential use of leguminous cash crops (e.g. soybean and cowpea) instead of maize and green manure legumes in rotation with maize. This aided in building an understanding of the key drivers of the system in Zimbabwe and Malawi. The outcomes showed that under low levels of soil fertility, the most efficient and lower risk decision was to plant maize using a low plant population density.

For direct engagement with farmers, replication of the Australian program (FARMSCAPE) with smallholder farmers in southern Africa was carried out (Carberry *et al*., 2002). Farmer participation was encouraged to address soil fertility management issues at the smallholder level (Twomlow, 2001). This was to explore the complementarities between farmer participatory research approaches and computer-based simulation modelling for ICRISAT-Bulawayo in Zimbabwe in 2001 (Carberry *et al.,* 2004; Whitbread *et al.,* 2004). The above approaches were tested by six teams made-up of crop modellers and researchers trained in participatory rural research and rural tools and methods, as well as local researchers knowledgeable about African farming systems (Whitbread *et al.,* 2010). The participatory tools were used to build realistic farming scenarios for the computer simulations by engaging farmers in order to obtain their reactions and suggestions for improvements in farm practice. According to Robertson *et al*. (2005) farmers in Zimbabwe found the system to be impractical and were unlikely to adopt the system, whereas in Malawi the green manure system was established to have higher reliability since the area enjoys higher rainfall.

APSIM was also used to explore system constraints, while creating opportunities with researchers and agents of smallholder farmers in highly constrained resource situations (Whitbread *et al.,* 2010). The approach was to develop farm scale models that considered resource situations and the impacts on productivity in order to determine optimal management strategies that could maximise efficiency. An alternative approach was developed in an attempt to capture the key interactions and constraints that determine productivity within a farm system. In these systems, APSIM was used to develop an understanding of the key drivers of the maize crop and how it would most efficiently respond to nitrogen fertiliser. Results showed that the efficient fertiliser response of maize depended on weeding at the time of nitrogen application.

APSIM’s outputs were used in the generation of information for policy makers, banking and insurance institutions as well as service providers (Carberry, 2005; Dimes & Twomlow, 2007). The study demonstrated how APSIM can be applied in exploring risk to financing cropping loans. Simulation of alternative management scenarios and the subsequent analysis by means of probability of non-exceedence graphs were useful to financial institutions (MacLeod *et al*., 2008).

Shamudzarira and Robertson (2002) used APSIM to simulate the response of maize to nitrogen from 1991-1998 at the Makoholi research station in Zimbabwe. The model was used as an analytical tool to explore the combination between nitrogen (N) fertiliser and management strategies in order to minimize risk. Maize growth and development in response to nitrogen was simulated with a degree of accuracy, while the model results were used to analyse risk associated with nitrogen use. Statistically, the simulated results indicated a negative response of nitrogen in 15% of years within the long-term record, whereas no negative response to nitrogen was recorded in the field trials. Results for both measured and simulated yields revealed a median response of 20-30 kg maize grain kg^{-1} N applied. Results also suggested that reasonable rates of N application (30 kg N ha^{-1}) would give better responses per unit N applied than smaller N applications such as 15 kg N ha^{-1}. No evidence was found that fertiliser strategies, conditionally based on rainfall, would present significant profit over fixed application strategies. However, proper agronomic practices (soil tillage, cultivar selection, planting date, fertiliser application rate, and weed control) do assist in the realisation of nitrogen input returns.

2.3 Factors influencing maize production

In South Africa, maize is produced under diverse environmental conditions with about 60% of the maize being white and 40% yellow (Du Plessis, 2003). Maize production depends on the correct application of management practices ensuring both environmental and agricultural sustainability. According to Sangoi (2001) it is important to better understand the link between maize physiology and its optimum management strategies. Suitable hybrids, optimum plant population, planting dates, plant nutrition and timely weeding are crop management factors that are important to achieve optimum crop yields (Subedi & Ma, 2009). Du Toit *et al*. (1999) summarised the state of maize production on the highveld of South Africa. The average production of maize on a commercial scale yields between 1 000 and 3 000 kg ha^{-1} in the drier western half of the country. The breakeven yields for commercial farmers in the western Highveld are just above 2 000 kg ha^{-1}. The low productivity of dryland (rainfed) maize could be attributed to a combination of factors such as low soil fertility, unfavourable climatic conditions and poor farm management during the growing season (Major *et al*., 1991). Mati (2000) stated that inputs such as fertilisers, seed quality and cultural management activities are all important factors for rainfed maize production in semi-arid regions. Therefore, the factors considered in this project are climate, soil, planting date, plant population density, fertiliser application rate and weeding.

2.3.1 Climate

The daily temperatures, seasonal rainfall, day length, solar radiation and humidity are major climatic factors affecting maize production in semi-arid regions (Allan, 1971). Furthermore, global warming has already lead to changes in the local climate and its variability and will ultimately impact on grain yield (Molua & Lambi, 2006). Climatic conditions could also raise issues of sustainability of maize production at a regional and national level in South Africa (Du Toit *et al*., 1999). Uncertainty of maize yield scenarios could be influenced by the sensitivity of the crop to climate variability which affects farming practices (Du Toit *et al.,* 1999).

The distribution of global solar radiation such as photosynthetic active radiation (PAR) and net all-wave radiation influences the growth and development of maize plants. Solar radiation provides the free energy required by plants for growth and maintenance through the process of photosynthesis (Hall, 2001). Sangoi (2001) found that solar radiation can be used to identify the management decisions that allow maximising crop growth in an environment. Solar radiation can be transformed into grain production, while the duration of day length also influences the flowering and growth of shoots of crop plants.

Most processes in plants that relate to growth and yield are highly dependent on temperature, since the optimum temperature for photosynthesis frequently corresponds to the optimum growth temperature (Molua & Lambi, 2006). Crop yields can be affected positively or negatively by temperature increases. Maize is a warm weather grain crop, since the plants develop optimally at temperatures around 30^{o}C. At temperatures below 6^{o}C and above 45^{o}C the process of photosynthesis comes to a standstill (Du Plessis, 2003). High temperatures shorten the life cycles of grain crops, resulting in a shorter grain filing period. High temperatures could also produce smaller and lighter grains, culminating in lower crop yield and poor grain quality (Wolfe, 1995; Adams *et al*., 1998 cited in Molua & Lambi, 2006). Extremely low temperatures will cause frost conditions which can damage maize at all growth stages. To prevent frost damage to crops, a 120 to 140 day frost-free period is required (Du Plessis, 2003).

Rainfall is the most important climatic factor that influences the pattern and productivity of rainfed maize in sub-Saharan Africa, since rainfall replenishes soil water used by crops (Amissah-Arthur, 2003; Molua & Lambi, 2006). A number of climatic factors such as low and erratic rainfall, constant low humidity levels and high temperatures during the growing season have influenced crop growth conditions (Botha *et al.,* 2003). Du Toit *et al.* (1999) stated that erratic rainfall and drought are more difficult to manage, since their occurrence is less predictable, while the response of maize to climate depends on the physiological make-up of a variety/cultivar being grown. The variability of seasonal rainfall total and climate change increases the vulnerability of maize production. The final maize yield is affected by the amount and distribution of rainfall and the amount of water transpired by the crop canopy (Matzenaner *et al.,* 1998 cited in Sangoi, 2001). Maize requires between 450 and 600 mm of rain per season, which is mainly acquired from the soil moisture reserves (Du Plessis, 2003). Maize plants can easily reach the soil moisture reserves, since the total root length of maize extends to an estimated 2 metres for a mature crop (Du Plessis, 2003). Maize production under rainfed conditions could be affected by the timeliness, adequacy and reliability of seasonal rainfall (Walker & Schulze, 2006). Under rainfed conditions an annual rainfall of 350 to 450 mm is required to produce a maize yield of 3 tonnes per hectare (Du Plessis, 2003). Ramadoss *et al*. (2004) found that rainfed maize production was severely impeded by water stress and high temperatures even if the soil water profile was full at the beginning of the growing season. Akpalu *et al*. (2008) found that a 10% reduction in mean rainfall reduced the mean maize yield by approximately 4% in South Africa.

2.3.2 Soil

Maize production requires suitable soil that has sufficient and balanced quantities of plant nutrients and chemical properties, effective depth, favourable morphological properties, good internal drainage, and an optimal moisture regime (Du Plessis, 2003). The interaction of soil physical, chemical and biological properties in various soils could prompt the occurrence of soil degradation which affects maize yields (Doran & Parkin, 1994; Halvorson *et al*., 1996 cited in Wick *et al.,* 1998). This could be results in the form of erosion, losses of nutrients or soil compaction which is extreme alarm to agricultural production (Liu *et al*., 2010). Pagliai *et al*. (2004) and D'Haene *et al*. (2008) also highlighted that the degradation of agricultural soils threatened sustained production, are consequences of decreases of loss of soil structure and organic matter. Vlek *et al*. (1997) pointed out that the loss of organic matter and stored nutrients, as a result of cultivation, causes a loss in crop productivity. In order to maximise maize production it is important to assess the soil nutrient status frequently (every second year) to determine how much fertiliser should be applied (Ofori & Kyei-Baffour, 2004).

The effect of water shortages on production will vary with crops, the soil characteristics, the root system, and the severity and timing of moisture stress during the growing cycle (Ahn, 1993; Molua & Lambi, 2006). Ofori and Kyei-Baffour (2004) found that to maximise maize yield, the soil water profile throughout the growing season should be around or above 50% of the available water capacity in the rooting zone. Soil water stress usually hampers the growth and development stages of maize such as flowering, pollination and grain filling, which is critical in determining crop yield (Molua & Lambi, 2006). Soil compaction is another factor that directly or indirectly affects the growth and yield of crops, especially maize. This decreases plant root penetration, movement of water and nutrients through factors such as bulk density, porosity and penetration resistance of soil (Alakukku & Elonen, 1994; Ishaq *et al*., 2003). Soil compaction can be reduced through soil preparation at planting using deep tillage systems to improve water infiltration and nutrient movement in the soil (Bennie & Botha, 1986). Deep tillage and selection of crop rotation with deep-rooted crops (such as maize) can be options for management practices for remediation of subsoil compaction (Motavalli *et al*., 2003).

Soil characteristics in the root zone are crucial as it affects soil water and nutrient availability (Grewal *et al.*, 1984). Fine textured (clayey) soils generally have a higher soil organic matter content than coarse textured (sandy) soils, since the bond between the surface of clay particles and organic matter delay the decomposition process (Bot & Benites, 2005). Prasad and Power (1997 cited in Bot & Benites, 2005) found that under specific climate conditions, the organic matter content in fine textured soil is 2-4 times that of course textured soils. Another critical factor influencing crop production is acidification. Acidification is also caused by leaching of the basic plant nutrients (e.g. calcium, potassium and magnesium) and limits the uptake of these elements while aluminium toxicity in the soil also damage plant roots (Awad *et al.,* 1976; Adams, 1984). Soil acidity is the main cause of soil degradation in South Africa, where it reduces crop production drastically for small and large-scale agriculture (Beukes, 1997 cited in Materechera & Mkhabela, 2002). Extremes in soil pH (acid or alkaline) could result in poor biomass production and in reduced additions of organic matter to the soil (Bot & Benites, 2005) due to poor growing conditions for micro-organisms in the soil. This will result in low levels of biological oxidation of organic matter, which affects the availability of plant nutrients and thus indirectly biomass production (Bot & Benites, 2005). Soil pH controls crop performance, especially for maize where plants are sensitive to acidity of the soil (Arsova, 1996). Generally the most suitable soil pH for maize is between 6.0 to 7.5, while the plants can tolerate soil pH levels between 5.5 and 8.0 (FSSA, 2007). The solution to soil acidity is liming, which reduces the toxic concentration of aluminium and manganese and increases the soil pH. Most importantly, liming improves the solubility and availability of plant nutrients (Biswas & Mukherjee, 1994 cited in Onwuka *et al.,* 2007).

2.3.3 Planting date

Planting date plays a significant role in influencing the growth and yield of maize (Beiragi *et al.,* 2011). Maize growers have a challenge in finding the planting window that is neither too early nor too late (Nielsen *et al.,* 2002). Selection of planting date is the most important management tool under rainfed production in South Africa (Du Plessis, 2003). Planting date is mainly linked to the long-term climatic conditions of the region (Pannar, 2006). Since planting date affect the timing and duration of the vegetative and reproductive stages, small-scale farmers tend to use multiple planting dates over extended periods of time to ensure that at least part of the crop is successful (Rohrbach, 1988; El-Gizawy, 2009). Therefore, small-scale farmers select early maturing varieties that offer flexibility in planting dates (Pswarayi & Vivek, 2007). The late planting of early maturing varieties helps during a delayed onset of rainfall to avoid terminal drought during the cropping season (Herbek *et al*., 1986).

In temperate and subtropical regions of the world, maize is planted early with a high plant density to maximise grain yield (Aldrich *et al*., 1986). Under these conditions the pattern of development of early planted maize is slower due to low soil and air temperatures (Sangoi, 2001). In South Africa, the potential plant dates for rainfed production in the summer rainfall region is from October (east) to December (west) (Walker & Schulze, 2006). This could lead to a risk of yield reduction when using early or late planting dates for rainfed maize production. Delaying planting dates could affect the growth and development of maize during later stages of the season due to frost occurrence. Beiragi *et al.* (2011) found that different planting dates have an effect on the growth and development of maize plants, modified by environmental changes such as solar radiation and temperature.

In a field experiment in central South Africa, it was found that greater leaf area index (as LAI) and dry matter accompanied by higher plant heights were achieved using early planting dates (Kgasago, 2006). Kgasago (2006) also found that early planting dates resulted in higher grain yield and yield components such as cob number, cob length and cob mass. In contradiction to Kgasago's (2006) findings, early hybrids in the tropics produced shorter plants with, fewer leaves and lower leaf areas, resulting in fewer self-shading plants than late hybrids. This means that the crop cannot utilise maximum interception of solar radiation in order to maximise grain yield (Sangoi, 2001). The probability exists that unfavourable climatic conditions that occur after planting or during the growing season could drastically lower maize yield or cause crop failure regardless of the planting date (Beiragi *et al.,* 2011). Due to unanticipated climatic conditions during the growth and development of maize, farmers could utilise multiple planting dates to avoid crop failure or unprofitable maize yield.

2.3.4 Plant population density

Maize is the agronomic grass species most sensitive to variations in plant population density (Sangoi, 2001). Du Plessis (2003) emphasised that maize plant population density would differ on account of soil fertility, varying climatic conditions, row spacing and cultivar type. Climatic conditions and cultivar types could be used to modify the optimum plant population density. Under southern

African conditions plant population density is generally low (15 000 to 35 000 plants ha^{-1}) (Raemaekers, 2001). Under cooler, temperate and warmer regions the plant population densities required to produce maize yields of 3 000 kg ha^{-1} are 19 000 plants ha^{-1}, 16 000 plants ha^{-1} and 14 000 plants ha^{-1}, respectively. For a yield of 6 000 kg ha^{-1} under cooler, temperate and warmer regions the plant population densities are 37 000 plants ha^{-1}, 31 000 plants ha^{-1} and 28 000 plants ha^{-1}, respectively (Du Plessis, 2003). The use of plant population density to increase maize yield gained popularity (Randhawa *et al*., 2003). Maize plants respond well to high plant populations up to a critical optimum number of plants per unit area. This is due to the fact that maize plants have a small capacity to develop new reproductive structures in response to an increase in the available resources per plant (Edmeades & Daynard, 1979; Loomis & Connor, 1996).

Maize yield could fall drastically by increasing plant population, since too high plant densities result in limited availability of resources (e.g. solar radiation, nutrients and water) per plant during the period of silking (Andrade *et al*., 1999; Vega *et al*., 2001). Light penetration in the crop canopy can be reduced by high plant population densities, which could displeasure the crop net photosynthesis process which may reduce grain yield (Azam *et al*., 2007). Yield may also be reduced as a result of a decline in harvest index and increased stem lodging caused by plant population density beyond the optimum level (Tollenaar *et al*., 1997). Weeds can dominate and lower grain yields if the applied plant population density was too low (Khan, 1972). Tollenaar (1992) acknowledge that to obtain maximum yield, planting early maturing hybrids rather than late maturing hybrids could help since early maturing maize hybrids favour a higher plant population.

The optimum plant density for maize grain yield could also be affected heavily by uncontrollable factors such as water availability when farming operations occur under rainfed conditions (Loomis & Connors, 1996). The interaction between soil water, plant population and rainfall could influence vegetative crop growth up to silking (Sangoi, 2001). High air temperatures and erratic rainfall that leads to drought stress could also affect maize yield due to interplant competition for water (Sangoi, 2001). Under such conditions it is advisable to use lower plant population densities (Sangoi, 2001). Using high plant population densities does not guarantee mean higher grain yields even if water supply is increased, since small deficiencies in water supply during critical growth stages, such as flowering and kernel set could drastically reduce grain yield (Sangoi, 2001). Farmers realise the importance of knowing the optimum plant population for their region and accompanied cropping system, based on the guidance of water use by crops. Considering the interactions of management and environmental factors, the optimum plant population can be increased by reducing row width to an equidistant planting pattern. Where this combination is implemented, the potential to increase maize yield may be achieved (Sangoi, 2001).

2.3.5 Fertiliser application rate

The application of fertilisers to improve or maintain soil fertility is essential for crop growth, development and also required to sustain profitable yields. Soil fertility declined over southern and eastern Africa, causing a dominant limitation to yield improvement and sustainability of maize production systems (Kumwenda *et al.,* 1996). Balanced nutrient management can improve fertiliser use and crop growth (Chen, 2006). Optimum fertiliser application rate is required, since poor growth and low yield could be prompted by shortages in nutrients, while too much fertiliser could lead to insignificant increases in grain yield (Walker *et al*., 1995). The solution to nutrient shortages could be the application of micronutrients (e.g. calcium, magnesium and baron manganese) without neglecting the macronutrients (nitrogen, phosphorus and potassium) (Ofori & Kyei-Baffour, 2004). Integrated nutrient management could stimulate sustainable agriculture using soil micro-organisms. This regulates the dynamics of organic matter decomposition and the availability of plant nutrients (Chen, 2006). Nitrogen stress reduces photosynthesis by reducing leaf area and accelerates leaf senescence. Inadequate nitrogen is the second biggest constraint after drought in tropical maize production, since maize has a strong positive response to nitrogen supply (Lafitte, 2000). Crops can uptake nitrogen from biological nitrogen fixation or microbial mineralisation in the form of nitrate (NO_3^-) and ammonium (NH_4^+) (Mengel & Kirkby, 1987; Vermoesen *et al*., 1993).

The soil nitrogen will vary between season and location (Lory & Scharf (2003). This may influence the soil nitrogen status, water availability, and plant population density of maize, while factors such as soil temperature and water will affect the application of nitrogen (Westerman *et al*., 1999; Al-Kaisi & Yin, 2003). Interactions between environmental factors could cause a variation in soil characteristics which leads to a variation in the optimum rate of nitrogen application required for maize (Mamo *et al*., 2003; Katsvario *et al*., 2003). At the beginning of the season, nitrogen supply usually exceeds nitrogen demand by the crop, but as the season progresses nitrogen in the soil will start to deplete, causing a nitrogen scarcity and nitrogen stress (Sangoi, 2001). Timing of plant nitrogen stress in the growing season could affect grain filling and kernel weight (Bänziger *et al*., 2000). Effective use of starter fertiliser will improve early growth and maize yield due to increased early season dry matter production (Vetsch & Randall, 2002; Niehues *et al*., 2004).

2.3.6 Weeding

Weeds are undesirable plants that interfere with human activities in cropped and non-cropped regions (FAO, 1994). With the introduction of agriculture, weeds were able to adapt well to any environment dominated by humans and even though they are not planted intentionally, they influence crop production (Harlan, 1992). Crop yield and quality are affected by weeds growing among crop plants, thereby causing high economic losses (Alam, 1991). The type of weed, weed density, persistence and crop management practices determine the magnitude of yield loss (Raiz *et al*., 2007).

Optimum grain yield dependents on proper weed control and include mechanical, chemical or biological methods (Dogan *et al*., 2004). Other studies (Shakoor *et al*., 1986; Correa *et al*., 1990; Owen *et al*., 1993; Dogan *et al*., 2004) indicated that chemical weed control is the most effective method, while mechanical weed control is still useful but expensive and time consuming. Mechanical control can also cause crop injury and soil erosion (Hurle, 1996; Tortenson, 1996). An alternative method of weed control is to integrate weed management, which involves the combination of two or more of the mentioned weed control methods (Akobundu, 1992; 1996). Integrated weed control methods (chemical and mechanical) could increase production cost and negatively affect the agro-ecosystem when applied intensively (Dogan *et al*., 2004). Integrated weed management practices such as crop rotation, cover crops, intercropping, manipulation of nitrogen fertilisers and alternative planting patterns (e.g. conservation tillage system) can be used as biological methods of weed control (Akobundu, 1992; 1996).

It is important that farmers know the critical period of weed control and calculate the associated economic thresholds of weeding (Ullah *et al*., 2008). The most crucial period of weed competition is six to eight weeks after crop emergence (MacRobert *et al.,* 2007). Farmers should keep their field weed free or control weeds when plants are between 3-leaf and 14-leaf stage (Hall *et al.,* 1992). High plant population density of maize could be used to reduce weed biomass during the growing season, since a high leaf area index (LAI) of maize will reduce the amount of light reaching shorter weeds (Tollenaar *et al*., 1994).

2.4 Review of management practices for rainfed maize production in the central Free State

The management practices for maize production in the central Free State province were assessed with the help of Mr. Dries Kruger, an agronomist at SENWES cooperative in Bloemfontein. Table 2.1 indicates the different cultivars of short and medium growing hybrids planted in the central Free State.

Table 2.1: Maize cultivars planted in the central Free State province

Short growing cultivars	Medium growing cultivars
PAN 6126 (YM)	CRN 3503 (WM)
PHB31B13 (YM)	CRN 3549 (WM)
PHB 3394 (YM)	DKC 7818 (WM)
PHB 32A05 (WM)	DKC 8010 (YM)
PHB 32A03 (WM)	DKC 8012 (YM)
	PAN 6146 (WM)
	PAN 6053 (WM)
	PAN 6479 (WM)
	PHB 3442 (YM)

(YM = Yellow Maize and WM = White Maize)

The central Free State is a semi-arid region where maize production under rainfed conditions is strongly affected by cultivar choice. The timing of planting dates can be used to minimise factors that could interfere with the maize plant during the growing season, such as dry spells during sensitive vegetative or reproductive growth stages. The general practice is to plant medium growers between 1 November and 20 December and short growing cultivars between 20 December and 30 December.

Most of the maize producers use a specific plant population density based on the cultivar duration and targeted potential yield. For medium hybrids commonly used the plant population densities are 11 500, 12 500, and 14 000 plants ha^{-1}, while 14 000 and 16 000 plants ha^{-1} can be used for short growing hybrids. Row spacing is one of the factors influencing grain yield, where narrow rows could usually be associated with higher maize yields when weeding is done. The row spacing under rainfed maize production can be linked to soil fertility, where a row width of 2.3 m per row is used for low potential soil and 1.5 m per row for higher potentials soils. Row spacing for maize under rainfed conditions vary from 0.91, 1.52 to 2.25 m, while the planting depth range from 40 to 70 mm.

Fertilisation is one of the most important management inputs in maize production, since its application affects grain yield. Farmers could predict optimum fertiliser application rate using the amount of nitrogen withdrawn from the soil for each ton of grain produced, considering that only grain is removed. For maize this withdrawal value is 15 kg N per ton of maize produced (Kruger, 2011[1]). This nitrogen is usually applied by the small-scale farmers in the form of LAN (28% N) and Urea (46% N). The application practices of fertiliser (N levels) for maize production under rainfed conditions could also be adjusted using row spacing. For a 0.9 m row spacing the required fertiliser application rate should not be more than 40 kg N ha^{-1}, while for 1.5 and 2.1 m rows fertiliser application rate should not exceed 30 and 20 kg N ha^{-1} respectively, at a yield potential of 3 - 4 t ha^{-1} (FSSA, 2007).

Weed control is essential since weeds compete with maize for resources such as soil water and nutrients, causing restricted plant growth and eventually reducing grain yield. Weed control can be in the form of mechanical, chemical or biological means. The recommended practice to control weeds is to apply a herbicide spray once after planting. Four to six weeks after crop emergence, mechanical weed control can be executed and the practice can be repeated once, twice or even three times depending on the nature of the season, the size of the crop and the width of rows.

The most important factors affecting maize production were highlighted in this chapter and included climate, soil, planting date, plant population density, fertiliser application rate and weeding. In order to optimise crop production, farmers in semi-arid regions could alter the management practices. The mentioned management practices will be employed in the next chapter to set up APSIM in order to validate and simulate maize yields.

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CHAPTER 3 METHODOLOGY

3.1 Site selection

The Modder River catchment is a semi-arid tertiary catchment with a total area of 1.73 x 10^6 ha. It is divided into three sub-basins, namely the upper, middle and lower Modder and the area is located to the east, west and north of the city of Bloemfontein, South Africa (Woyessa *et al*., 2006). The Modder River catchment has high seasonal rainfall variability with low and erratic rainfall, resulting in conditions that are marginal for rainfed maize production. The tertiary catchment of the Modder River (C52) comprises of 11 quaternary catchments (QCs). Selection of QCs was limited to areas where rainfed maize production takes place. From the number of QCs that qualified, the decision was made to choose five QCs that provide a fair spatial representation and fall within different land types. The five selected QCs within the Modder River catchment were C52B, C52C, C52G, C52H and C52J (Figure 3.1). Details of the selected QCs and their associated soil types are summarised in Table 3.1.

Table 3.1: Details of the selected sites within the QCs

QC	Land type	Site	Latitude (^{o})	Longitude (^{o})	Altitude (m)	Soil form	Soil series
C52B	Dc17	Near Thaba N'chu	29^o 29' 00" S	26^o 79' 00'' E	1 500	Swartland	Swartland (Sw31)
C52C	Dc17	Thaba N'chu	29^o 05' 37'' S	26^o 54' 33" E	1 500	Arcadia	Gelykvlakte (Ar20)
C52G	Ea39	Glen	28^o 57' 00" S	26^o 20' 00'' E	1 425	Swartland	Swartland (Sw31)
C52H	Ca22	Bainsvlei	29^o 08' 12'' S	26^o 07' 20'' E	1 425	Bainsvlei	Bainsvlei (Bv36)
C52J	Ca22	Leeukop	29^o 08' 12'' S	26^o 17' 28" E	1 425	Valsrivier	Lindley (Va41)

Land types are areas that are considered homogeneous in terms of terrain form, soil pattern and climate and should be identifiable on a 1:250 000 map (Land Type Survey Staff, 2010). All three land types (Dc17, Ea39 and Ca22) occur in the vicinity of Bloemfontein. Consequently they have similar descriptions in terms of climate classification, vegetation type and geological formations. Under the Köppen climate classification these land types are described as mesothermal (with an average annual temperature < 18°C) and semi-arid with summer rainfall. The vegetation is predominantly highveld grassland. Dominant geological groups/formations include sandstone, shale and mudstone of the Beaufort Group with dolerite intrusions (Land Type Survey Staff, 2010). Dc17 has a total area of 239 080 ha. The soil pattern within Dc17 consists of duplex soils with a prominent textural contrast between sandier topsoil and a blocky to prismatic structure subsoil, while black and red clay soils are also present. Present soil types are Swartland, Valsrivier, Milkwood, Bonheim, Estcourt, Sterkspruit, Arcadia and Mispah. Land type Ea39 covers a total area of 123 300 ha. Black, structured, swelling and non-swelling clay soils and red structured clay soils are found in this land type, while present soil types include Valsrivier, Milkwood, Bonheim, Sterkspruit, Arcadia, Swartland, Dundee, Oakleaf, Shortlands, Mispah and Hutton. Land type Ca22 has a total area of 156 400 ha. The soil pattern in Ca22 consists of plinthic soils (with subsurface accumulation of iron and manganese oxides over a fluctuating water table) with a high base status. Upland duplex soils (with a prominent textural contrast between the topsoil and subsoil) and black clay soils are common, while common soil types include Valsrivier, Westleigh, Milkwood, Avalon, Hutton, Sterkspruit, Mispah, Glenrosa and Bainsvlei (Land Type Survey Staff, 2010).

The Swartland form consists of an orthic A-horizon, followed by pedocutanic B- and saprolite horizons. The clay content of the Swartland series (Sw31) varies from 35 to 55% in the B-horizon. The colour of the series is non-red and it is not calcareous in the B- and C-horizons. The Arcadia form only has a vertic A-horizon, which is dark in colour. The surface tends to crust easily and the A-horizon is calcareous. The sequence of diagnostic horizons in the Bainsvlei form is an orthic A-horizon, followed by red and soft plinthic B-horizons. The clay content of the Bainsvlei series (Bv36) varies from 15 to 35%. The Valsrivier form consists of an orthic A-horizon, followed by a pedocutanic B-horizon and unconsolidated material. The clay content of the Lindley series (Va41) varies from 35 to 55% in the B-horizon. The colour of the series is predominantly non-red and it is calcareous in the B- or C-horizons. More information on these soil types can be obtained from Macvicar *et al*. (1977).

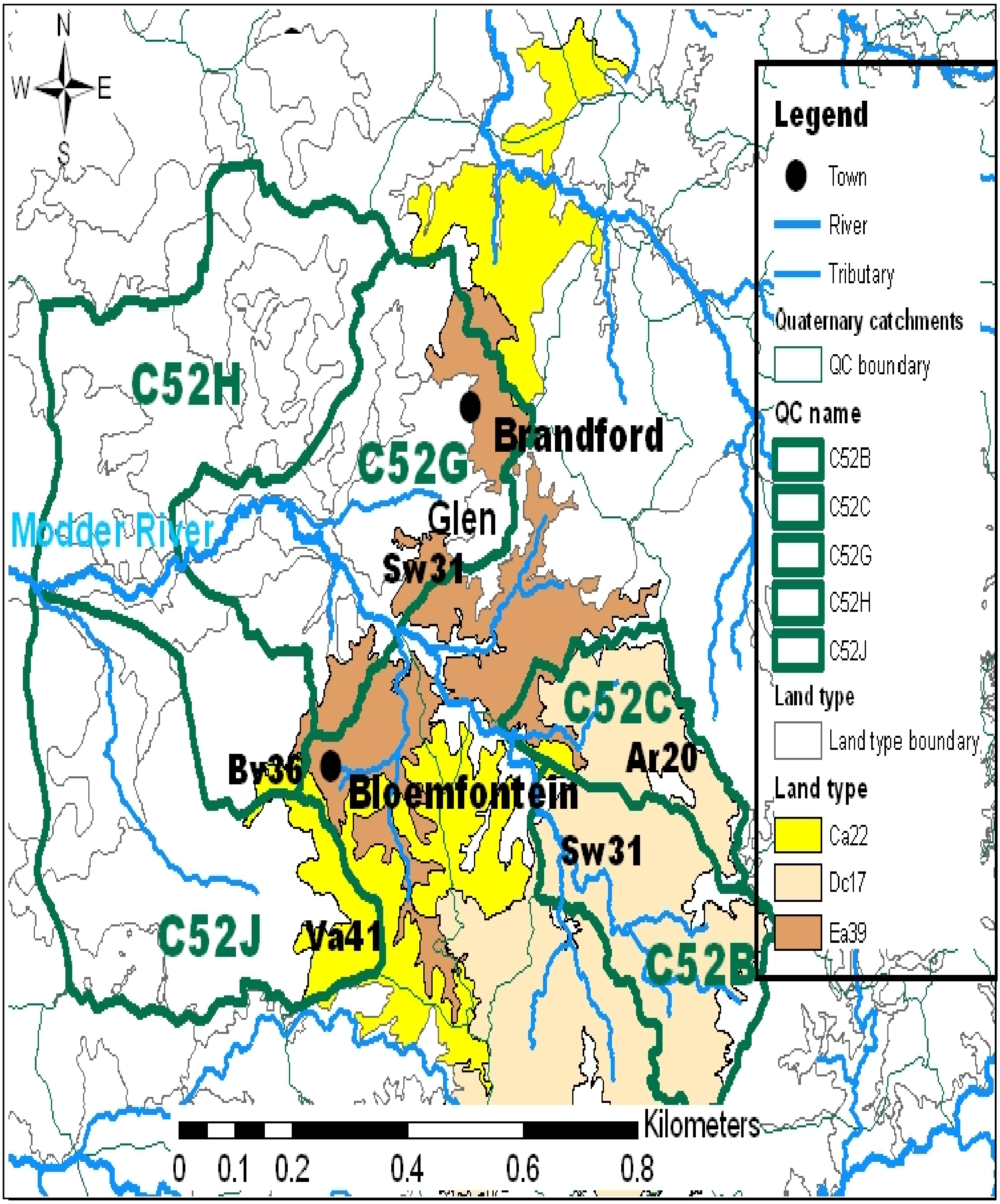


Figure 3.1: The Modder River catchment indicating various soil types and land types within the selected quaternary catchments.

3.2 Climate Analysis

The climate data used in this study was obtained from the QC database developed by the University of KwaZulu-Natal (Schulze *et al.,* 2005). This database contains 50 years (1950 to 1999) of daily hydro-climatological data such as daily rainfall, minimum and maximum temperatures, solar radiation and reference evapotranspiration. These variables are also meteorological parameters required by APSIM to simulate growth and development of the crops. Other studies (Schulze *et al*., 2007; Schulze, 2007; Schulze & Walker, 2007; Walker & Schulze, 2006) also used this dataset as input to simulate agro-hydrological responses and agricultural production in South Africa.

The rainfall data contained in the QC database was compiled by Lynch (2004) as part of a project sponsored by the Water Research Commission (WRC). Lynch (2004) acquired the initial rainfall datasets developed for another WRC project by Dent *et al*. (1989) and updated it annually till 2000. That information was obtained from an assortment of organisations and individuals that include, among others, the South African Weather Service (SAWS) which also supplied the data for Lesotho and Swaziland (8 281 stations), the Agricultural Research Council (ARC) (2 661 stations), the South African Sugarcane Research Institute (SASRI) (161 stations) as well as a number of municipalities, private companies and individuals (1 050 stations). All of these stations have not collected data concurrently (Lynch & Schulze, 2007). For the period in question (1950-1999) the SAWS and ARC automatically allocated the 24-hour rainfall measured at 06:00 GMT to the previous day during which the bulk of it may have fell (Steyn, 2008).

The data were checked by Lynch and Schulze (2007) for incorrect recording of the time and date at which the gauge was read and suspect extreme daily rainfall events. In the case of missing records, four infilling techniques were employed, viz. an expectation maximisation algorithm, a median ratio method, an inverse distance weighting and a monthly infilling technique for rainfall less than 2 mm (Lynch, 2004). After missing rainfall values had been filled in and the station records extended by the different infilling techniques, Lynch (2004) employed a Geographically Weighted Regression (GWR) approach in order to estimate rainfall values at those points on a raster grid where no stations with observed data or infilled values existed.

For each QC, Lynch (2004) determined a centroid using ArcView GIS. The Daily Rainfall Extraction Utility (DREU) developed by Kunz (2004 cited in Lynch & Schulze, 2007) was used to extract the ten nearest rainfall stations to each pair of the centroid's co-ordinates. These 10 stations are ranked by the DREU using a number of criteria including the distance from the rainfall station to the point of interest, station recording period and reliability (i.e. the percentage of actual data vs. infilled values). The best ranked station was selected as the so-called "driver" rainfall station, with that station's data considered representative of the daily rainfall of that QC (Lynch & Schulze, 2007).

All the QCs within the Modder River catchment falls under the same climate zone which means that the long-term climatic variables are similar. The climatic variables for each QC such as the long-term annual averages for rainfall, maximum temperature, minimum temperature, solar radiation and reference evapotranspiration are summarised in Table 3.2.

Table 3.2: Summarised climatic variables for each quaternary catchment

Climatic elements	**Quaternary Catchment**				
	C52B	**C52C**	**C52G**	**C52H**	**C52J**
Total annual rainfall (mm)	532	486	464	442	454
Average annual maximum temperature (^{o}C)	23.5	23.8	24.9	24.9	24.8
Average annual minimum temperature (^{o}C)	7.1	7.0	7.6	7.6	7.7
Average annual solar radiation (MJ m^{-2} d^{-1})	19.8	20.1	20.4	20.5	19.8
Total annual reference evapotranspiration (mm)	1416	1449	1518	1524	1515

The daily rainfall was used to construct two 3-month totals for each QC, namely October to December (OND) and January to March (JFM). These two 3-month periods is thought to comprise the summer growing season for maize. The seasonal rainfall is considered to influence the growing period and development stages of maize. The long-term (49 years) 3-month rainfall totals were sorted in ascending order and assigned cumulative probabilities to create a Cumulative Distribution Function (CDF) for each QC. These CDFs were used to determine the first, second and third tercile values which constitute the thresholds for above-normal (AN), near-normal (NN) and below-normal (BN) rainfall. This means that the lower threshold of the NN category is defined by the rainfall total corresponding to a cumulative frequency of 0.33 (or a probability of non-exceedence of 33.3%). The upper threshold of the NN category is defined by the rainfall total corresponding to a cumulative frequency of 0.66 (or a probability of non-exceedence of 66.6%). By dividing the CDFs into three equal parts (terciles) the thresholds for 3-month rainfall totals (as well as the simulated maize yields discussed in section 3.4) could be related directly to seasonal rainfall forecasts. A similar approach was followed by Moeller *et al*. (2008) to evaluate the potential value of hypothetical categorical forecasts of seasonal rainfall.

Sequential 3-month rainfall totals were subsequently grouped into one of the analogue seasons (OND followed by JFM) as detailed in Table 3.3. Since QC C52G was reserved for model validation (discussed in section 3.3), the number of analogue seasons within the other 4 QCs were tallied and presented in Table 3.4. It immediately became apparent that sensible statistical analyses of simulated maize yields could not be performed on a single QC's results as some analogue seasons occurred only a small number of times within certain QCs (e.g. 3 AN-NN seasons in C52J). After careful consideration the decision was made to combine analogue seasons across the 4 QCs presented in Table 3.4 in order to increase the sample population size (total number of analogue seasons within the 49-year period). For example, by combining analogue seasons across QCs it was possible to increase the number of AN-AN years from the initial 4 to 5 per QC to a total of 19. By combining analogue seasons across QCs it was also possible to increase the overall number of growing seasons from the initial 49 per QC to a staggering 196.

Table 3.3: Combination of 3-month rainfall scenarios to create analogue seasons for the summer growing season

Rainfall Scenario	OND rainfall conditions		JFM rainfall conditions
AN-AN	Above-normal		Above-normal
AN-NN	Above-normal		Near-normal
AN-BN	Above-normal		Below-normal
NN-AN	Near-normal	**followed by**	Above-normal
NN-NN	Near-normal		Near-normal
NN-BN	Near-normal		Below-normal
BN-AN	Below-normal		Above-normal
BN-NN	Below-normal		Near-normal
BN-BN	Below-normal		Below-normal

Table 3.4: Number of growing season rainfall scenarios per QC

Rainfall Scenario	Quaternary Catchment				Total
	C52B	**C52C**	**C52H**	**C52J**	
AN-AN	4	5	5	5	19
AN-NN	9	5	4	3	21
AN-BN	5	7	7	8	27
NN-AN	7	5	4	5	21
NN-NN	4	8	6	10	28
NN-BN	4	4	5	3	16
BN-AN	5	5	8	6	24
BN-NN	6	6	6	5	23
BN-BN	5	4	4	4	17
Total	49	49	49	49	196

3.3 Validation of APSIM

Obtaining observed maize yield data and their associated management practice was a huge stumbling block. Initially it was hoped to obtain such data from Glen College of Agriculture outside Bloemfontein. Unfortunately, such data was never forthcoming. Actual maize yield data (kg ha^{-1}) for the 1980/81 to 2004/2005 seasons was provided by Department of Agriculture, Forestry and Fisheries (DAFF) for the Bloemfontein region. Unfortunately, agricultural practices used to produce these yields were not available. This dataset was used to validate the simulated maize yields. The decision was made to produce several ensembles of the simulated maize yields using a fairly wide range of plausible management practices based on the information contained in section 2.4 (Table 3.5).

Table 3.5: Plausible management practices used to validate APSIM

Management practices	Treatments
Planting date	1-15 November; 16-30 November; 1-15 December; 16-30 December
Fertiliser application rate (kg ha-1 N)	35; 50; 75; 100
Plant population density (plants ha-1)	12 000; 14 000; 16 000; 18 000
Weeding frequency (times per growing season)	1; 2; 3

After careful evaluation it was decided to use the climatological data from the weather station at Glen College of Agriculture. The soil data used to create the soil module in APSIM was the Swartland series of the Swartland form (Sw31) under the land type Ea39 (Table 3.1).

Within APSIM's maize module, there was only one medium growth period cultivar which is actually planted in Free State province. This cultivar, PAN 6479, reaches maturity after 109-119 days (Pannar, 2006). According to an APSIM expert at CSIRO the Australian maize cultivar Pioneer 3237 contained within APSIM exhibits similar characteristics to those planted in rainfed production in South Africa (Hargreaves, 2009[2]). Pioneer 3237 is a medium growth period cultivar that reaches maturity after 116-119 days (O' Gara, 2007). Subsequently, two medium growth period maize cultivars were used to validate APSIM, namely PAN 6479 and Pioneer 3237.

Five days was allowed for seed-bed preparation by means of a disk. For each planting period (Table 3.5), sowing of maize took place within APSIM when 20 mm of rainfall was accumulated within a 5-day period and the soil water content was 30 mm or more. If these two criteria were not met sowing proceeded on the last day of the window period. The model initialization for sowing depth and row spacing was 70 mm and 1.5 m, respectively. Fertiliser application rate was done at sowing using LAN (28) as a source of N. Within APSIM, weeds were simulated as an intercrop. Dicotyledonous (dicot) weed varieties were assumed to grow under a plant population density of 5 plants m^{-2}. For each planting period (Table 3.5),

[2] John Hargreaves, 2009. Crop modeller at CSIRO, Australia. Email: John.Hargreaves@csiro.au

sowing of weed took place within APSIM when 10 mm of rainfall were accumulated over a 5-day period and the soil water content was 5 mm or more. These conditions had to be satisfied after each weeding control event. Weed control was done 22 days after weed emergence using mechanical procedures.

The model was subsequently applied under rainfed conditions to simulate maize yields for PAN 6479 and Pioneer 3237 from 1980/81 to the 2004/2005 growing seasons. The simulated maize yields were analysed and compared to the measured maize yields to validate APSIM over the study area. The statistical methods described by Willmott (1981; 1982), Willmott *et al.* (1985), Wilks, 1995; Mendenhall and Sincich (2003), Rinaldi *et al.* (2003), Willmott and Matsuura (2005) and Willmott *et al.* (2009) and Willmott *et al.* (2011) were used to validate APSIM. The following indices were used to evaluate model performance:

- Coefficient of determination (R^2);
- Mean Error (ME);
- Root Mean Square Error (RMSE);
- systematic and unsystematic Root Mean Square Error (RMSEs and RMSEu);
- Index of agreement (d); and
- Modelling efficiency.

Coefficient of determination (R^2) can be computed from the following equation:

$$R^2 = \frac{SSR}{SST} = 1 - \frac{SSE}{SST}$$

where SSR is the regression sum of squares, SST is the total sum of squared deviations of the predicted values around their mean, and SSE is the sum of squared differences between the residuals/errors and their means (Wilks, 1995). Qualitatively, R^2 can be interpreted as that portion of the variation of the predictand (proportional to SST) that is “described” or “accounted for” by the regression (SSR) (Wilks, 1995; Mendenhall & Sincich, 2003). For a perfect regression, SSR = SST and SSE = 0, so that R^2 = 1. For a completely useless regression, SSR = 0 and SSE = SST, so that R^2 = 0. In such a case the least-squares regression line is almost indistinguishable from the sample mean of the predictand, so SSR is very small, and little of the variation in the forecast predictand can be ascribed to the regression (Wilks, 1995).

Mean Error (ME) was used to investigate averaged differences between the simulated and the corresponding measured maize yields. It is calculated as:

$$ME = n^{-1}\sum_{i=1}^{n}(p_i - o_i)$$

where n is the number of observations, p_i and o_i are simulated (predicted) and measured (observed) maize yields. ME it is not only used to measure the average magnitude of the errors in the set of simulated maize yields, but also to consider their direction.

Willmott (1982), Willmott *et al.* (1985), Willmott and Matsuura (2005) and Willmott *et al.* (2009) described the Root Mean Square Error (RMSE) as a good overall measure of model performance. It provides information about the actual size of errors produced by the model. It is calculated as:

$$RMSE = \sqrt{n^{-1}\sum_{i=1}^{n}(p_i - o_i)^2}$$

Low values of RMSE indicate that the maize yields were well simulated, thus explaining most of the variation in the measured maize yields. RMSE does not indicate the source or type of errors and it is therefore useful to define a systematic Root Mean Square Errors (RMSEs) and unsystematic Root Mean Square Error (RMSEu), given by:

$$RMSE_S = \sqrt{n^{-1}\sum_{i=1}^{n}(y_i - o_i)^2}$$

$$RMSE_U = \sqrt{n^{-1}\sum_{i=1}^{n}(p_i - y_i)^2}$$

where y_i is derived from $y_i = a + bo_i$.

Willmott (1981; 1982) and Willmott *et al.* (1985) found that the RMSEs represent the average error produced by the model. Large RMSEs values showed there was a bias in the model, while RMSEs values approaching zero indicated the model performed well. The closer RMSEu to the RMSE, the better the model's performance, under such conditions the deviations of simulated maize yield from measured maize yield are random.

Willmott (1981; 1982), Willmott *et al.* (1985) and Willmott *et al.* (2011) also used the index of agreement (d) to measure the degree to which the model's predictions were error free. It was calculated as:

$$d = 1 - \frac{\sum_{i=1}^{n} (p_i - o_i)^2}{\sum_{i=1}^{n} (|p'_i| - |o'_i|)^2} \quad 0 \le d \le 1$$

where $|p'_i| = |p_i - \bar{o}|$ and $|o'_i| = |o_i - \bar{o}|$. ($\bar{o}$ is the mean of the measured maize yields)

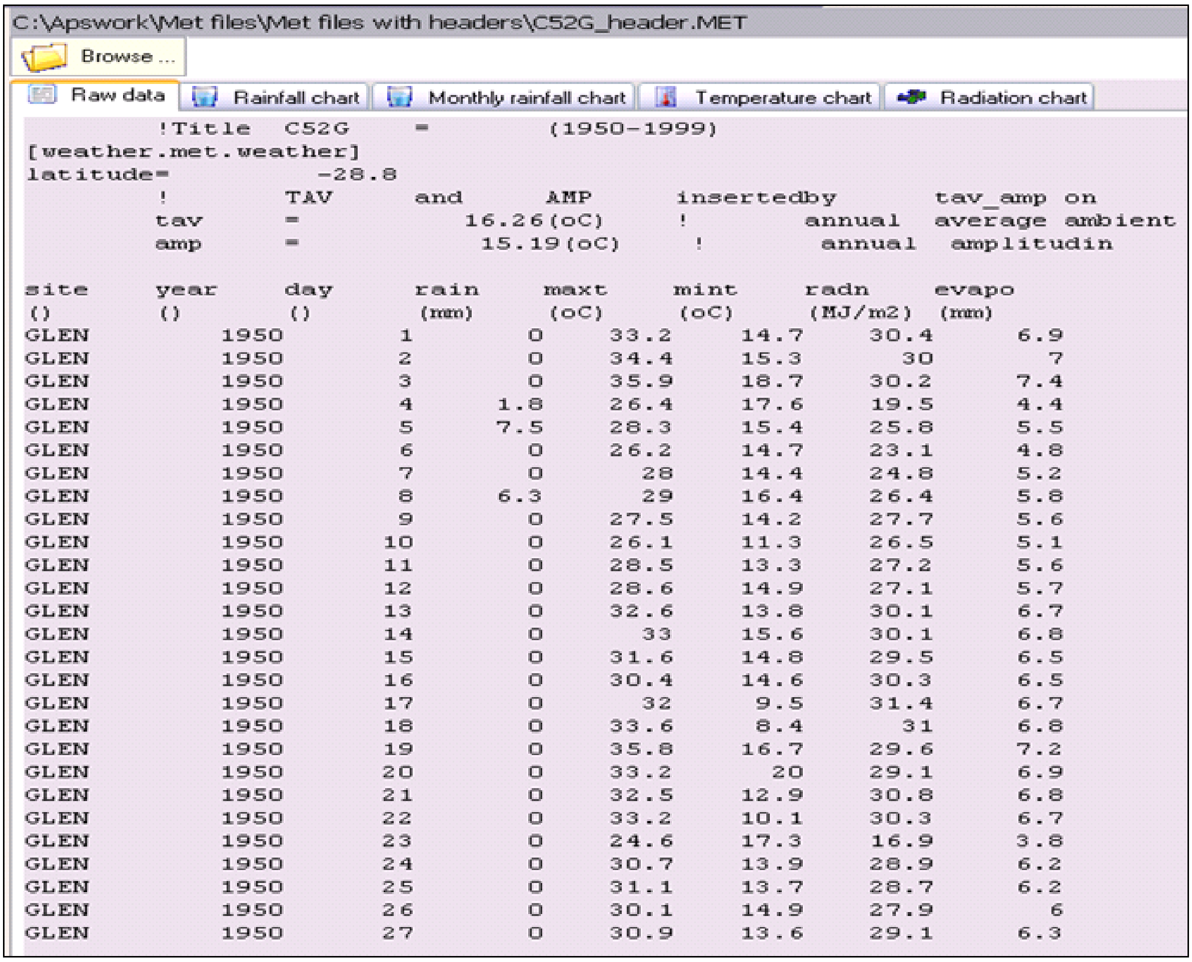
The index of agreement varies between 0 (complete disagreement) and 1 (complete agreement between the measured and simulated maize yields).
Modelling Efficiency compares the variability between simulated and measured maize yields, where the variability ranges from 0 to 1. It was calculated as:

$$Modelling \;\; efficiency = \frac{\sum (o_i - \bar{o})^2 - \sum (p_i - o_i)^2}{\sum (o_i - \bar{o})^2}$$

A negative value of the modelling efficiency indicates that the simulated variability is greater than the measured variability and therefore, the model is not satisfactory (Rinaldi *et al.,* 2003).

3.4 Simulation of maize yield using APSIM

The first step in the simulation process was to create the meteorological (met) files containing the required daily values for rainfall, minimum and maximum temperatures, solar radiation and reference evapotranspiration. The annual average ambient temperature (TAV) and the annual amplitude in monthly temperature (AMP) were calculated using long-term daily minimum and maximum temperatures. The calculated values of TAV and AMP were inserted in the met files by the software program named 'tav_amp'. The raw data in the met file was arranged according to used site location (name), latitude (^{o}), years, days, rainfall (mm), minimum and maximum temperature (^{o}C), reference evapotranspiration (mm d^{-1}), solar radiation (MJ m^{-2}), TAV and AMP as shown in Figure 3.2.




```
          !Title   C52G    =        (1950-1999)
[weather.met.weather]
latitude=          -28.8
          !        TAV      and      AMP      insertedby       tav_amp on
          tav      =           16.26(oC)      !        annual  average ambient
          amp      =            15.19(oC)     !         annual  amplitudin

site      year     day      rain     maxt     mint     radn     evapo
()        ()       ()       (mm)     (oC)     (oC)     (MJ/m2)  (mm)
GLEN        1950       1        0     33.2     14.7     30.4      6.9
GLEN        1950       2        0     34.4     15.3       30        7
GLEN        1950       3        0     35.9     18.7     30.2      7.4
GLEN        1950       4      1.8     26.4     17.6     19.5      4.4
GLEN        1950       5      7.5     28.3     15.4     25.8      5.5
GLEN        1950       6        0     26.2     14.7     23.1      4.8
GLEN        1950       7        0       28     14.4     24.8      5.2
GLEN        1950       8      6.3       29     16.4     26.4      5.8
GLEN        1950       9        0     27.5     14.2     27.7      5.6
GLEN        1950      10        0     26.1     11.3     26.5      5.1
GLEN        1950      11        0     28.5     13.3     27.2      5.6
GLEN        1950      12        0     28.6     14.9     27.1      5.7
GLEN        1950      13        0     32.6     13.8     30.1      6.7
GLEN        1950      14        0       33     15.6     30.1      6.8
GLEN        1950      15        0     31.6     14.8     29.5      6.5
GLEN        1950      16        0     30.4     14.6     30.3      6.5
GLEN        1950      17        0       32      9.5     31.4      6.7
GLEN        1950      18        0     33.6      8.4       31      6.8
GLEN        1950      19        0     35.8     16.7     29.6      7.2
GLEN        1950      20        0     33.2       20     29.1      6.9
GLEN        1950      21        0     32.5     12.9     30.8      6.8
GLEN        1950      22        0     33.2     10.1     30.3      6.7
GLEN        1950      23        0     24.6     17.3     16.9      3.8
GLEN        1950      24        0     30.7     13.9     28.9      6.2
GLEN        1950      25        0     31.1     13.7     28.7      6.2
GLEN        1950      26        0     30.1     14.9     27.9        6
GLEN        1950      27        0     30.9     13.6     29.1      6.3
```

Figure 3.2: Example of a met file containing meteorological parameters for C52G (Glen).

APSIM includes modules on soil surface residue dynamics, with linkages to water and nutrient processes. The soil modules in APSIM are based on the international and African classification format. Soil forms from the Limpopo province were already included, but soil forms for the Free State were not available in APSIM since it has never been tested in this province. The soil module was created for the selected soils using information obtained from land type data created by the Land Type Survey Staff (2006). The APSIM soil module required soil properties such as the bulk density (BD), total porosity, saturation (SAT), organic carbon (OC), drained upper limit (DUL), crop lower limit (LL), plant available water capacity (PAWC) and pH to simulate maize yields. Table 3.6 through 3.10 provide information regarding the above-mentioned soil properties used to set up the soil modules for selected QCs. The coefficients of evaporation, unsaturated flow, runoff, organic matter, and erosion were estimated from the colour, texture and structure of the respective soils.

Table 3.6: Properties of the Sw31 soil series used in APSIM's soil module for C52B (the effective root zone for crops was considered to be 0-120 cm)

Soil properties						Maize and weeds	
Depth	**BD**	**SAT**	**DUL**	**OC**	**pH**	**LL**	**PAWC**
cm	**g cc^{-1}**	**mm mm^{-1}**	**mm mm^{-1}**	**%**		**mm mm^{-1}**	**mm**
0-10	1.50	0.32	0.086	0.175	6.03	0.035	5.10
10-20	1.50	0.32	0.098	0.175	6.03	0.035	6.30
20-30	1.50	0.33	0.122	0.290	6.03	0.050	7.20
30-50	1.43	0.36	0.166	0.522	6.10	0.062	20.80
50-70	1.43	0.37	0.198	0.522	6.90	0.088	22.00
70-90	1.42	0.38	0.220	0.452	7.84	0.110	22.00
90-110	1.54	0.30	0.200	0.422	8.84	0.110	18.00
110-120	1.54	0.30	0.200	0.422	8.84	0.110	9.00
Total							110.40

Table 3.7: Properties of the Ar20 soil series used in APSIM's soil module for C52C (the effective root zone for crops was considered to be 0-120 cm)

Soil properties						Maize and weeds	
Depth	**BD**	**SAT**	**DUL**	**OC**	**pH**	**LL**	**PAWC**
cm	**g cc^{-1}**	**mm mm^{-1}**	**mm mm^{-1}**	**%**		**mm mm^{-1}**	**mm**
0-10	1.50	0.32	0.113	0.421	6.03	0.035	7.80
10-20	1.50	0.32	0.126	0.421	6.03	0.035	9.10
20-30	1.50	0.33	0.144	0.440	6.03	0.045	9.90
30-50	1.43	0.36	0.165	0.535	6.10	0.067	19.60
50-70	1.43	0.37	0.188	0.535	6.90	0.120	13.60
70-90	1.42	0.38	0.188	0.452	7.84	0.120	13.60
90-110	1.54	0.30	0.199	0.422	8.84	0.110	17.80
110-120	1.54	0.30	0.200	0.422	8.84	0.110	9.00
Total							100.40

Table 3.8: Properties of the Sw31 soil series used in APSIM soil module for C52G (the effective root zone for crops was considered to be 0-120 cm)

Soil properties						Maize and weeds	
Depth	**BD**	**SAT**	**DUL**	**OC**	**pH**	**LL**	**PAWC**
cm	**g cc^{-1}**	**mm mm^{-1}**	**mm mm^{-1}**	**%**		**mm mm^{-1}**	**mm**
0-10	1.50	0.32	0.082	0.38	6.46	0.033	4.40
10-20	1.55	0.30	0.096	0.38	6.46	0.045	5.10
20-30	1.55	0.30	0.110	0.39	7.44	0.045	6.50
30-50	1.66	0.27	0.154	0.40	8.14	0.067	17.40
50-70	1.62	0.29	0.189	0.40	8.94	0.120	13.80
70-90	1.51	0.30	0.220	0.44	9.14	0.120	20.00
90-110	1.46	0.35	0.200	0.38	8.92	0.110	18.00
110-120	1.46	0.35	0.200	0.35	8.92	0.110	9.00
Total							94.40

Table 3.9: Properties of the Bv36 soil series used in APSIM's soil module for C52H (the effective root zone for crops was considered to be 0-120 cm)

Soil properties						Maize and weeds	
Depth	**BD**	**SAT**	**DUL**	**OC**	**pH**	**LL**	**PAWC**
cm	**g cc^{-1}**	**mm mm^{-1}**	**mm mm^{-1}**	**%**		**mm mm^{-1}**	**mm**
0-10	1.60	0.30	0.084	0.50	6.90	0.045	3.90
10-20	1.60	0.30	0.100	0.50	6.90	0.045	5.50
20-30	1.50	0.32	0.120	0.50	6.90	0.045	7.50
30-50	1.40	0.33	0.160	0.50	6.50	0.062	20.80
50-70	1.40	0.34	0.164	0.40	6.60	0.076	17.60
70-90	1.40	0.35	0.164	0.30	6.80	0.096	14.00
90-110	1.40	0.36	0.189	0.30	7.40	0.096	18.60
110-120	1.40	0.37	0.189	0.20	7.40	0.100	8.90
Total							96.80

Table 3.10: Properties of the Va41 soil series used in APSIM's soil module for C52J (the effective root zone for crops was considered to be 0-120 cm)

Soil properties						Maize and weeds	
Depth	**BD**	**SAT**	**DUL**	**OC**	**pH**	**LL**	**PAWC**
cm	**g cc^{-1}**	**mm mm^{-1}**	**mm mm^{-1}**	**%**		**mm mm^{-1}**	**mm**
0-10	1.55	0.30	0.098	0.82	8.07	0.056	3.90
10-20	1.50	0.32	0.110	0.78	8.80	0.061	5.50
20-30	1.50	0.32	0.140	0.76	8.80	0.061	7.50
30-50	1.45	0.34	0.164	0.72	8.90	0.090	20.80
50-70	1.45	0.34	0.182	0.70	8.94	0.092	17.60
70-90	1.40	0.36	0.185	0.69	8.98	0.098	14.00
90-110	1.40	0.36	0.199	0.68	9.03	0.100	18.60
110-120	1.40	0.37	0.240	0.66	9.13	0.100	8.90
Total							101.00

The weeds that grow within the Modder River catchment are summer dicotyledonous (dicot) weeds and may be annual, biennial or perennial in nature. The majority of weeds have broad and often toothed or divided leaves with netted venation (Das, 2009). A shortcoming in APSIM was that it did not have a summer dicot weed module. According to an APSIM expert in CSIRO (Hargreaves, 2009[3]), the winter dicot (as in section 3.5) module that existed in APSIM, did not differ much from the summer dicot weeds found in the study area. Therefore, the winter dicot weed module in APSIM was used to simulate weed response in the continuous maize and weed production module. As was the case for model validation, weeds were simulated as an intercrop. As before, sowing of weed at 5 plants m^{-2} took place within APSIM when 10 mm of rainfall was accumulated

[3] John Hargreaves, 2009. Crop modeller at CSIRO, Australia. Email: John.Hargreaves@csiro.au

over a 5-day period and the soil water content was 5 mm or more. If included as a management practice, the first weeding took place 22 days after weed emergence.

The manager module in APSIM was used to describe the management configurations before simulation took place. The management practices used for rainfed maize production in the Modder River catchment was discussed in section 2.4. The same maize cultivars (PAN 6479 and Pioneer 3237) used in the validation of APSIM were used to simulate maize yields for the entire 49-year period spanning 1950/51 to 1998/99. The cultivars used to simulate maize yields did not perform well during validation. The decision to continue using them stemmed from the fact that the actual yield data was obtained under different cultivars, soil types and management practices, where cultivars similar to PAN 6479 and Pioneer 3237 could be included. Yet, it was crucial to examine how the cultivars performed under historical climatic conditions and how alternative management practices in response to seasonal rainfall conditions could benefit small-scale farmers. The different management practices used to simulate maize and weed are summarised in Table 3.11. Similar specifications, in terms of seed-bed preparation, sowing criteria and fertiliser application rate were used as in the validation setup.

Table 3.11: Management practices used to simulate maize yields

Management practices	Treatments
Planting date	1-15 November; 16-30 November; 1-15 December; 16-30 December; 1-15 January
Fertiliser application rate (kg ha^{-1} N)	0; 35; 50; 75; 100
Plant population density (plants ha^{-1})	9 000; 12 000; 15 000; 18 000; 21 000
Weeding frequency (times per growing season)	0; 1; 2; 3

The model was subsequently applied under rainfed conditions from 1950/51 to 1998/99 growing seasons to simulate the maize yield using the various combinations of management practices summarised in Table 3.11. Maize growth was simulated on a daily time-step as the crop responded to climate, soil and nitrogen within the four QCs not used in the validation of the model. Simulated maize yields were allocated to analogue growing season rainfall scenarios as determined in the climate analysis (Table 3.3). Combining simulated maize yields that fell under the same analogue seasons were feasible because of the small variability in climate across the QCs (Table 3.2). Previous studies (Hammer *et al.*, 2001; Moeller *et al*., 2008) employed a similar method of clustering simulated yields according to analogue seasons. The use of analogue seasons made it possible to determine the optimal management practices under each seasonal rainfall scenario.

For each growing season rainfall scenario, the simulated maize yields under different management decisions were subjected to analysis using the stepwise linear regression method. This method was used to screen yield predictors (management practices) in order to determine which ones dominate the variation of simulated maize yields. Statistical Analytical Simulation (SAS) was used to accomplish this. The stepwise linear regression method selected those yield predictors that adhered to a partial R^2 value greater than 0.0001 at a significance level of 0.15.

Only those yield predictors selected by the stepwise regression method were ranked in order of descending partial R^2 values. CDFs were used to plot maize yields under different sets of yield predictors for various growing season rainfall scenarios. These probability graphs were used to read off the maize yields corresponding to probabilities of 25, 50 and 75%. This was used to identify the highest yielding set of management practices under each growing season rainfall scenario.

3.5 Assessing the comparative economic benefit of different management practices

It is understood that farmers aim to adopt a farming system that minimises risk while maximising production and profit. Field costs for maize production vary with different management practices, as shown in Tables 3.12 to 3.15. The costs of tillage practices such as ploughing, ripping, disking and planting (Table 3.12) were obtained from an agronomist at SENWES cooperative in Bloemfontein (Kruger, 2011[1]). These costs were estimated based on a tractor’s average diesel consumption per hectare (R7.90 per litre taken on 11 January 2011, Bloemfontein). Maintenance costs associated with each activity are also included.

Table 3.12: Field and maintenance costs associated with different tillage practices

Tillage practice	Field cost (R ha^{-1})	Maintenance cost (R ha^{-1})	Total cost (R ha^{-1})
Ploughing	18.32 L ha^{-1} X R7.90 L^{-1} =R144.73	R68.10	R212.83
Ripping	18.00 L ha^{-1} X R7.90 L^{-1} =R142.20	R61.22	R203.42
Disking	6.49 L ha^{-1} X R7.90 L^{-1} = R51.27	R41.40	R92.67
Planting	6.10 L ha^{-1} X R7.90 L^{-1} = R48.19	R95.30	R143.49

The total field and maintenance cost for ploughing, ripping, disking and planting was R652.41 ha^{-1}. Other important expenses that vary according to different combinations of management practices are seed, fertiliser and weeding costs. The seed price was R991.00 per 60 000 seeds for Pannar and R1 950.00 per 80 000 seeds for Pioneer (Kruger, 2011[1]). The prices provided in Table 3.13 were calculated according to the plant population densities that were used in the maize yield simulations (Table 3.11).

Table 3.13: Seed costs associated with different plant population densities

Number of seeds (ha^{-1})	Seed cost	
	Pannar (R ha^{-1})	Pioneer (R ha^{-1})
9 000	R148.65	R219.38
12 000	R198.20	R292.50
15 000	R247.75	R365.63
18 000	R297.30	R438.75
21 000	R347.85	R511.88

Limestone Ammonium Nitrate (LAN 28) as a nitrogen source was used at a cost of R210.10 per 50 kg (Kruger, 2011[1]). This implied a cost of R4.20 kg^{-1}. Table 3.14 indicates the fertiliser application rate costs based on the various N application that were used in the maize yield simulations (Table 3.11).

Table 3.14: Fertiliser (N) application costs

Fertilisation (kg ha^{-1} N)	LAN (28) (kg ha^{-1})	Cost (R kg^{-1} ha^{-1})
35	125.0	R525.00
50	178.6	R750.12
75	267.9	R1 125.18
100	357.1	R1 499.82

The cost of weeding was calculated by multiplying the diesel consumption per hectare for mechanical weeding with the diesel price (R7.90 per litre) and adding the maintenance cost. The weeding frequency was included in the calculation, as shown in Table 3.15. The total operational field cost was calculated by adding the first and second field costs.

Table 3.15: Costs corresponding to various weeding frequency

Weeding frequency	Weeding cost (R ha^{-1})	Maintenance cost (R ha^{-1})	Total costs (R ha^{-1})
1	1.9 L ha^{-1} X R7.90 L^{-1} = R15.01	R9.10	R24.11
2	3.8 L ha^{-1} X R7.90 L^{-1} = R30.02	R18.20	R48.22
3	5.7 L ha^{-1} X R7.90 L^{-1} = R45.03	R27.30	R72.33

For Pioneer 3237 and PAN 6479, the various sets of management practices exhibiting the highest yield potential were subjected to an economic analysis. The simulated maize yields were converted to net income values by multiplying them with the SAFEX maize price (R1 321.00 on 11 January 2011). The net income values (R ha^{-1}) obtained in this manner for different sets of management practices, were again allocated to analogue growing season rainfall scenarios (defined in Table 3.3) before they were subjected to further economic analysis.

Following the method described by Moeller *et al*. (2008), gross margins were calculated by subtracting the field costs from the net income values for each set of management practices. These gross margins were used to assess the economic benefit or loss of maize production for PAN 6479 and Pioneer 3237 under each analogue growing season. CDFs were used to plot gross margins under different sets of management practices. These probability graphs were used to determine the optimal set of management practices under each growing season rainfall scenario. Probability levels of 25, 50 and 75% were used to assess the financial risk and potential financial benefits.

3.6 Development of advisory practices for rainfed maize production based on various seasonal rainfall scenarios

Maize producers continually search for agronomic practices that will help them to increase yields, reduce input costs or a combination of both. The need to translate seasonal forecasts into advisories that convey information pertaining to the economic outcomes of different management practices was highlighted in section 1.1. Developing advisories for rainfed maize production, based on different growing season rainfall scenarios, is thought to address this need. After careful consideration it was decided that the advisories would be in the form of flow charts that could later easily be replicated by a software program.

The first part of the advisory flow chart involved describing the growing season rainfall scenario as explained in section 3.2. The idea was that farmers could either use:

- a 6-month seasonal forecast at the beginning of the growing season; or
- a 3-month seasonal forecast at a later stage in the growing season after assessing the rainfall for the first few months.

The second part of the advisory flow chart provided information regarding management practices. These were ranked according to their significance for maize yield prediction. In each case the best, second best and worst set of management practices were emphasised. The best option provided the highest gross margin (highest profit), while the next best option under each yield predictor was also provided in order to aid farmers should the best option not be viable. The worst option was associated with the lowest gross margin (biggest loss).

An economic analysis for the best and worst options of management practices were provided in the last part of the advisory flow chart. The economic analysis comprised of field costs, maize yield expectancy and the economic benefits (gross margins) under probability levels of 25, 50 and 75%.

CHAPTER 4 RESULTS AND DISCUSSION

4.1 Climate analysis

All QCs (C52B, C52C, C52G, C52H and C52J) within the Modder River catchment fell under one climate zone with similar long-term climatic variables. These were summarised by long-term climatic variables for each QC (Table 3.2 in section 3.2). The cumulative distribution functions (CDFs) for early summer rainfall (OND) and late summer rainfall (JFM) are illustrated in Figure 4.1 to Figure 4.5.

Above-normal conditions for QC C52B occurred when the rainfall totals for OND and JFM were more than 204.1 and 267.6 mm, respectively (Figure 4.1). Below-normal years were characterised by rainfall totals below 135.2 mm for OND and 183.6 mm for JFM. This means that during below-normal followed by above-normal years (BN-AN), the rainfall totals for OND were less than 135.2 mm followed by more than 267.6 mm for JFM.

Below-normal conditions for QC C52C (Figure 4.2) occurred when the totals for OND and JFM were less than 135.5 and 170.0 mm, respectively. Above-normal years are characterised by rainfall totals above 189.0 mm for OND and 237.0 mm for JFM. Figure 4.3 clearly illustrates that above-normal years for QC C52G were characterised by rainfall totals above 168.5 mm for OND and 250.3 mm for JFM. During below-normal years the expected rainfall conditions fell below 111.7 and 151.2 mm for OND and JFM, respectively (Figure 4.3).

Near-normal conditions occurred for QC C52H when the rainfall totals for OND were between 101.0 and 148.7 mm. For JFM the expected rainfall conditions were near-normal (NN) when it fell between 147.5 and 244.3 mm. Above-normal years were subsequently characterised by rainfall totals above 148.7 mm for OND and 244.3 mm for JFM (Figure 4.4). For QC C52J above-normal conditions occurred when the rainfall totals for OND and JFM were more than 143.0 and 244.8 mm, respectively (Figure 4.5). Below-normal years were characterised by rainfall totals below 100.8 mm for OND and 148.7 mm for JFM.

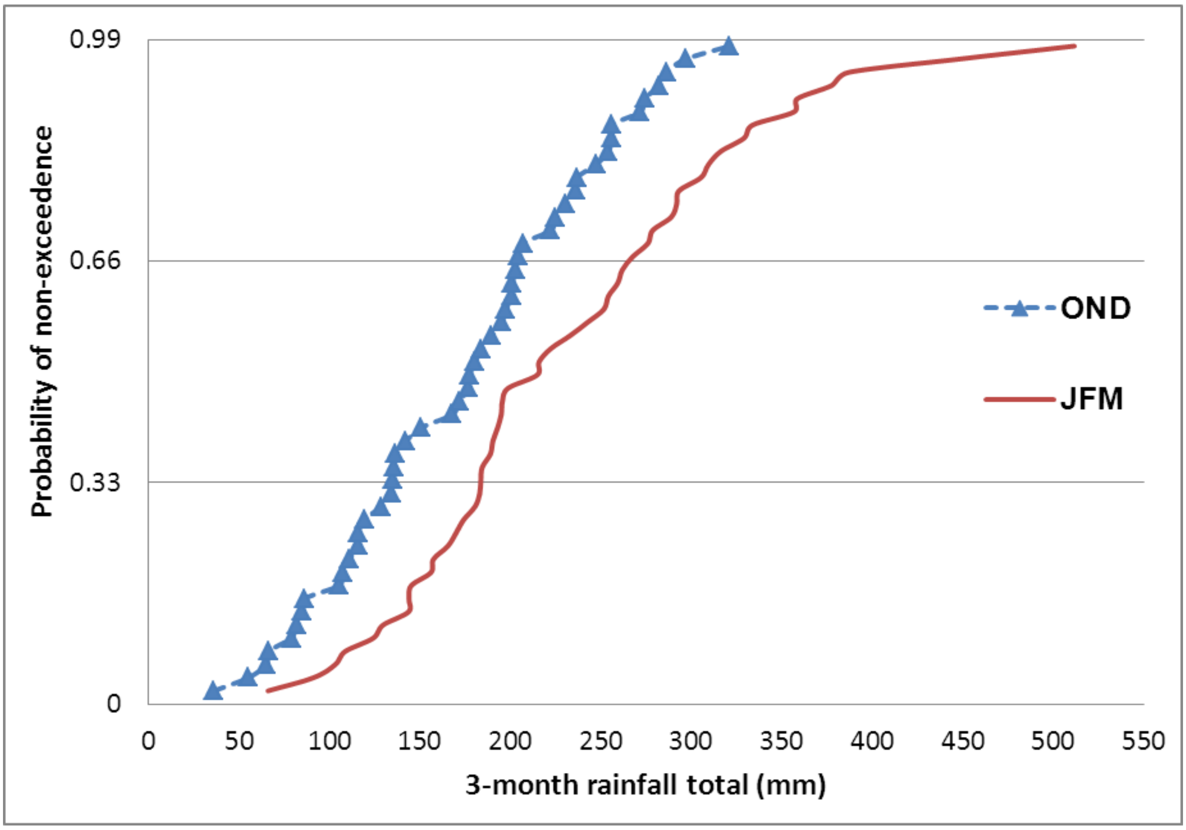


Figure 4.1: Cumulative distribution function of long-term 3-month rainfall totals for OND and JFM for C52B.

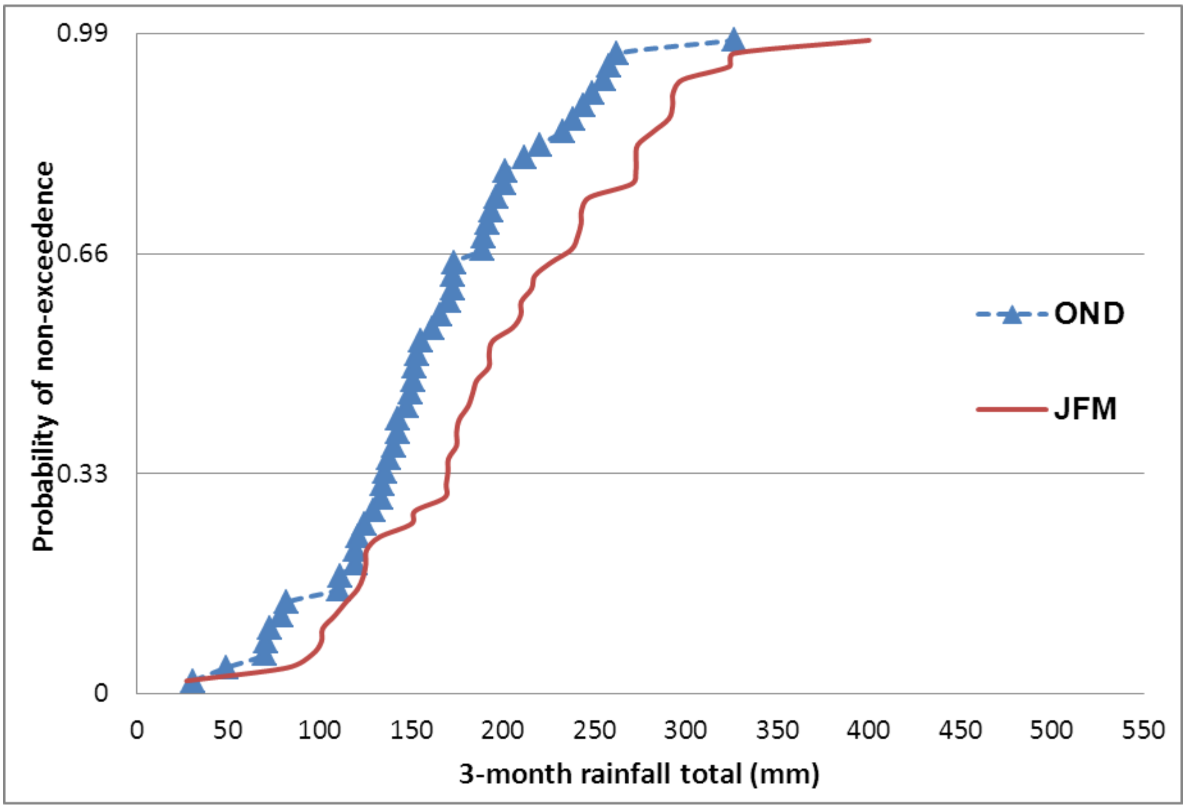


Figure 4.2: Cumulative distribution function of long-term 3-month rainfall totals for OND and JFM for C52C.

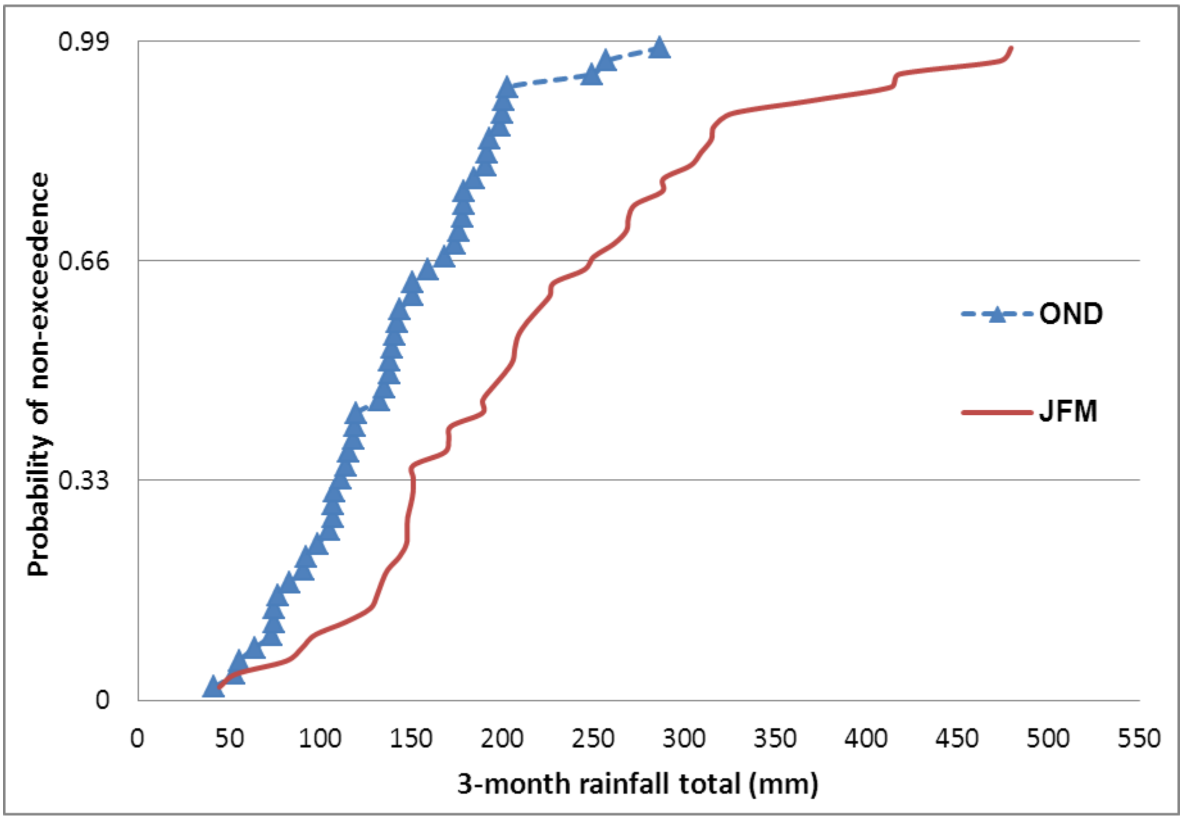


Figure 4.3: Cumulative distribution function of long-term 3-month rainfall totals for OND and JFM for C52G.

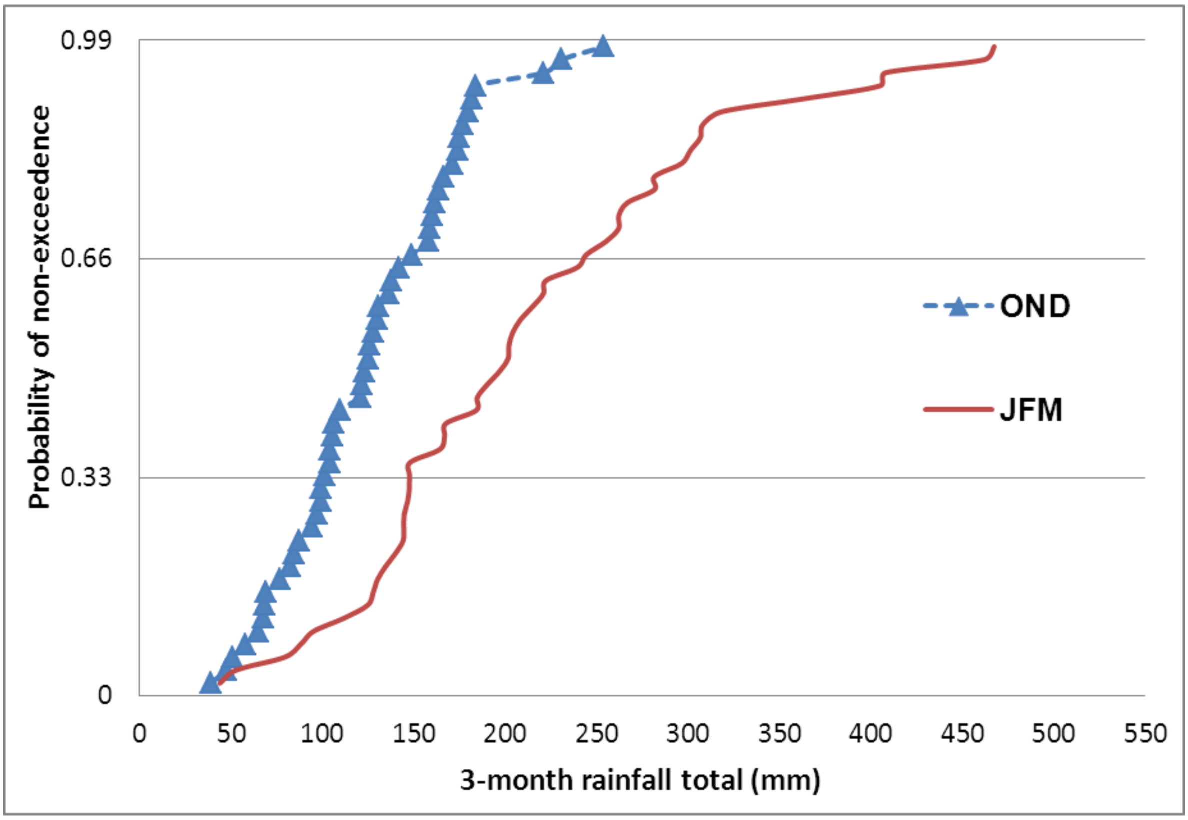


Figure 4.4: Cumulative distribution function of long-term 3-month rainfall totals for OND and JFM for C52H.

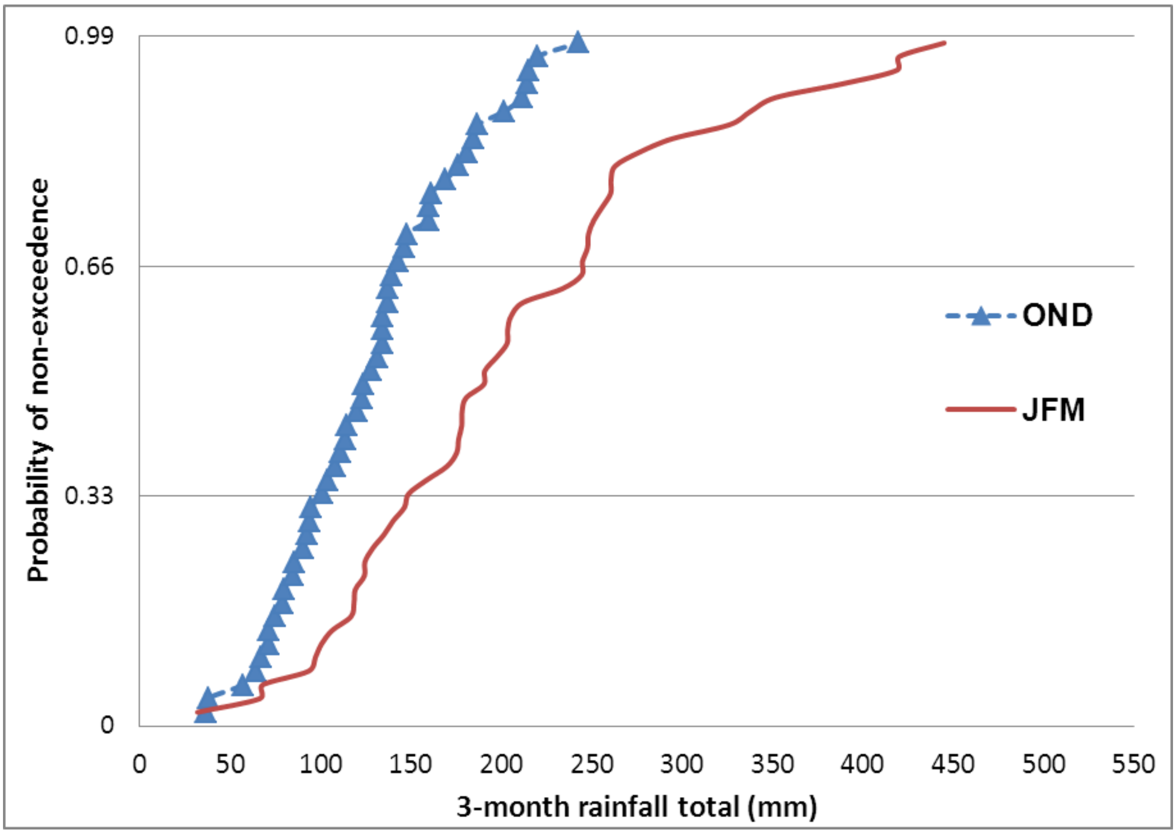


Figure 4.5: Cumulative distribution function of long-term 3-month rainfall totals of OND and JFM for C52J.

4.2 Validation of APSIM

4.2.1 Background

Agricultural field experimentation can only be used to investigate a limited number of management practices under specific climatic conditions. Knowing the limitations, crop growth models could still be used to evaluate the uncertainties of the production under various management practices, sites and climatic conditions (Timsina & Humphreys, 2006). Timsina *et al.* (2004) illustrated that by using crop growth model outputs in relation to climate, soil and management conditions a degree of sustainability in agricultural production can be achieved. The results of simulated agricultural production using crop growth models raised various questions by end-users. These concerns include the details of implementation, the approach and the validity of the simulated yields (Thorp *et al.*, 2007). According to Tingem *et al.,* (2009) it is reckless using crop growth models without testing and validating them for the sites where they will be applied. Validating a crop growth model is necessary since the outcomes of the validation will determine whether it is an acceptable representation of the real system, given the purpose of the simulation model (Kleijnen, 1999). The validation statistics used to evaluate the performance of APSIM were the coefficient of determination (R^2); mean error (ME), root mean square error (RMSE); systematic and unsystematic root mean square errors (RMSEs and RMSEu); the index of agreement (D); and modelling efficiency.

4.2.2 Evaluation of model performance

Validation of APSIM focused on the statistical relationship between measured and simulated maize yields from 1980/81 to 2004/05 for the Bloemfontein area. Two cultivars (PAN 6479 and Pioneer 3237) were used to simulate maize yields under various management decisions summarized in Table 3.5. The coefficient of determination (R^2) was used to analyse the linear relationship between the measured and simulated maize yields. As mentioned in section 3.3 information regarding the management practices employed during the respective growing seasons that lead to the observed (measured) yields could not be obtained.

The analysis of simulated and measured maize yields under different planting dates indicated that the R^2 decreased as the planting date shifted later in the season with combinations of other management practices for PAN 6479. The R^2 between measured and simulated maize yields under different management practices ranged from 0.66 to 0.07. Simulated maize yields during 1-15 November and 16-30 November were highly correlated with the measured maize yields for PAN 6479. The linear relationships between simulated and measured maize yields revealed a higher R^2 for high plant population densities during 1-15 November and 16-30 November, while the worst linear relationship was observed for low plant population densities (Figures 4.6 and 4.7). Figures 4.6 and 4.7 are scatterplots of simulated against observed maize yields for PAN 6479. Regression lines are indicated for different plant population densities, fertiliser application rates and weeding frequencies.

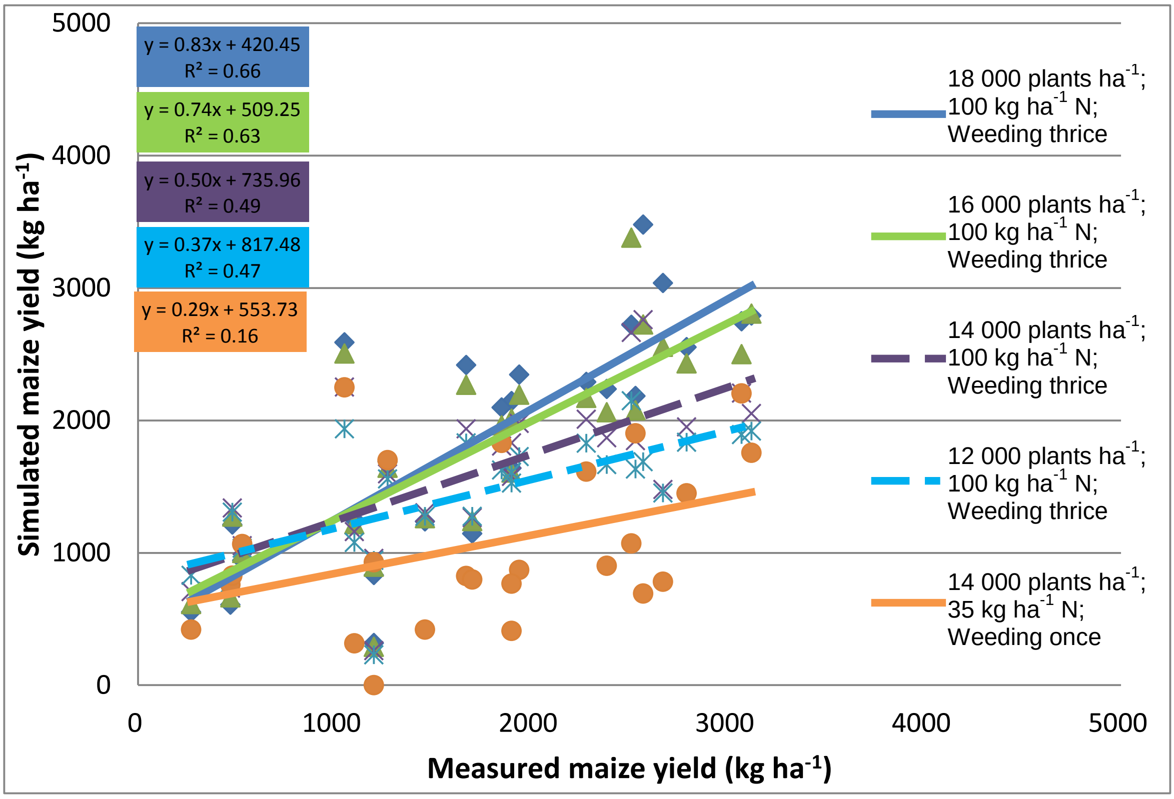


Figure 4.6: Relationship between measured and simulated maize yield for PAN 6479 under different plant population densities, fertiliser application rates and weeding frequencies (planted during 1-15 November).

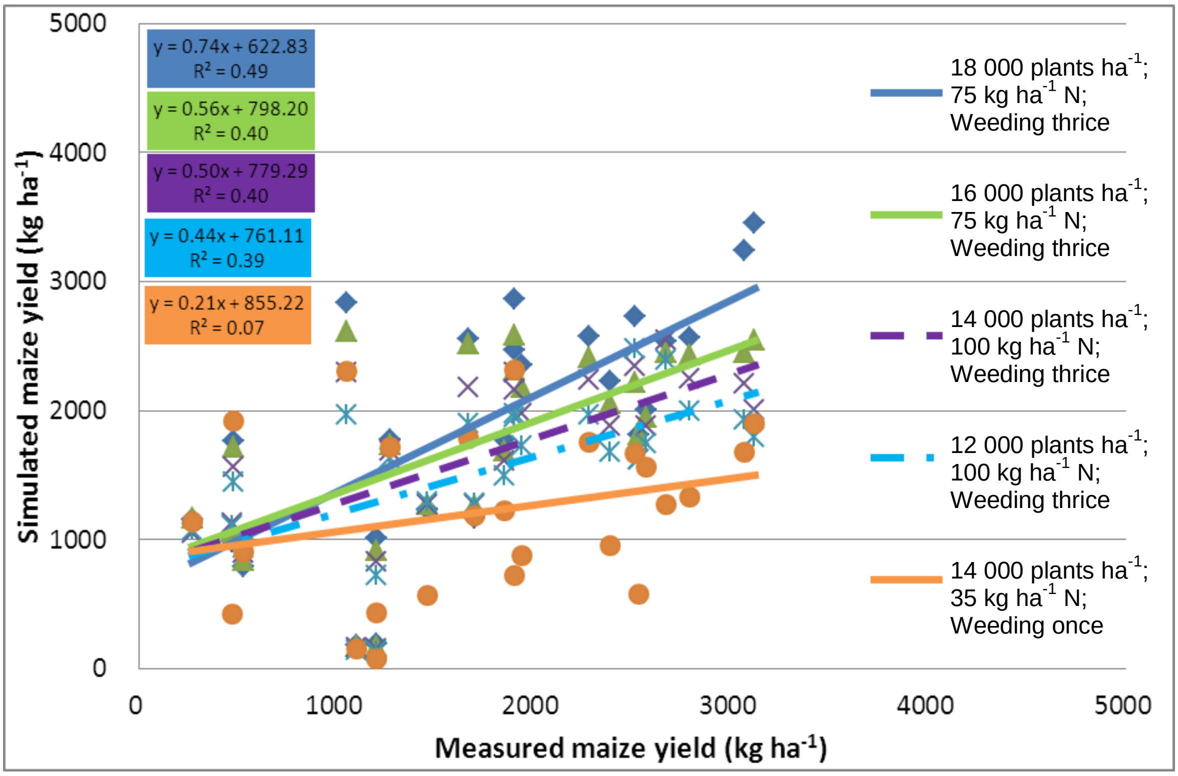


Figure 4.7: Relationship between measured and simulated maize yield for PAN 6479 under different plant population densities, fertiliser application rates and weeding frequencies (planted during 16-30 November).

A reasonable linear relationship exists between simulated and measured maize yields for the early planting date (1-15 November), a weeding frequency of 3 times, and maximum fertiliser application rate (average R^2 = 0.64) at 2 plant population densities (R^2 = 0.66 for 18 000 plants ha^{-1} and R^2 = 0.63 for 16 000 plants ha^{-1}). A poor correlation (R^2 = 0.16) existed between the recommended plant population density (14 000 plants ha^{-1}), a low fertiliser application rate (35 kg ha^{-1} N) and weeding once (Figure 4.6). Figure 4.7 indicates that planting during 16-30 November, the strongest correlation (R^2 = 0.49) was obtained with a plant population density of 18 000 plants ha^{-1}, a fertiliser application rate of 75 kg ha^{-1} N and weeding frequency of 3 times. At the same planting date (16-30 November) a poor correlation (R^2 = 0.07) was found between measured and simulated maize yields for a low fertiliser application rate (35 kg ha^{-1} N) and plant population density (14 000 plants ha^{-1}). Marginally better relationships between measured and simulated maize yields involved high fertiliser application rates (100 or 75 kg ha^{-1} N), high weeding frequencies (three times) and high plant population densities (18 000 or 16 000 plants ha^{-1}) (Figures 4.6 and 4.7).

The linear relationship between simulated and measured maize yields for Pioneer 3237 indicated that the R^2 also decreased as the planting date shifted later in the season under different combinations of management practices. The coefficients of determination between measured and simulated maize yields under different management practices ranged from R^2 = 0.42 to R^2 = 0.04. This indicated that the correlation between measured and simulated maize yields were lower than 0.5 even during those planting dates suitable for the short growing cultivar (20 to 30 December as indicated in section 2.4). Figures 4.8 and 4.9 illustrate the linear relationship between simulated and measured maize yields planted respectively during 1-15 November and 16-30 November. A slightly better correlation between measured and simulated maize yields involved planting 1-15 November using a high fertiliser application rate (75 kg ha^{-1} N) and weeding frequency (three times) in combination with high plant population densities (18 000 or 16 000 plants ha^{-1}) (R^2 = 0.42 in Figure 4.8). A poor relationship (R^2 = 0.04) was observed between measured and simulated maize yields when using a planting date between 16-30 November, fertiliser application rate of 50 kg ha^{-1} N, weeding frequency of one and plant population density of 12 000 plants ha^{-1} (Figure 4.9).

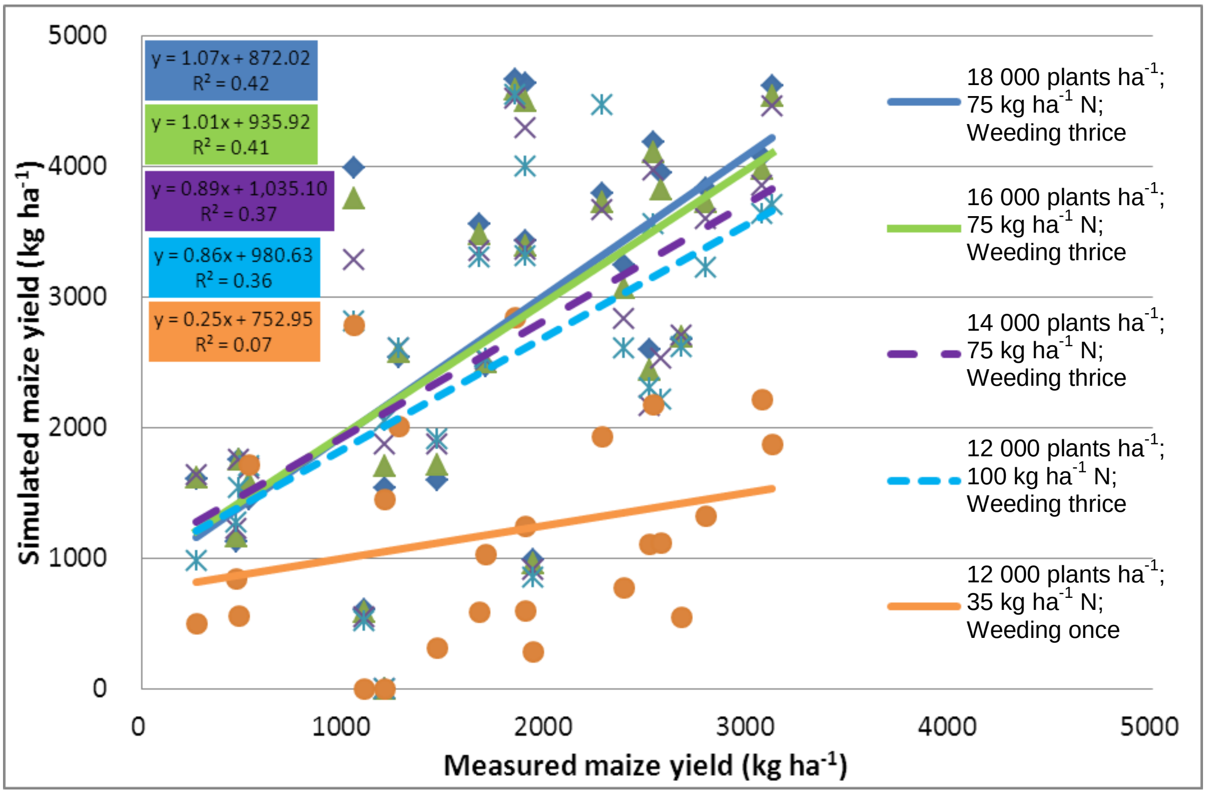


Figure 4.8: Relationship between measured and simulated maize yield for Pioneer 3237 under different plant population densities, fertiliser application rates and weeding frequencies (planted during 1-15 November).

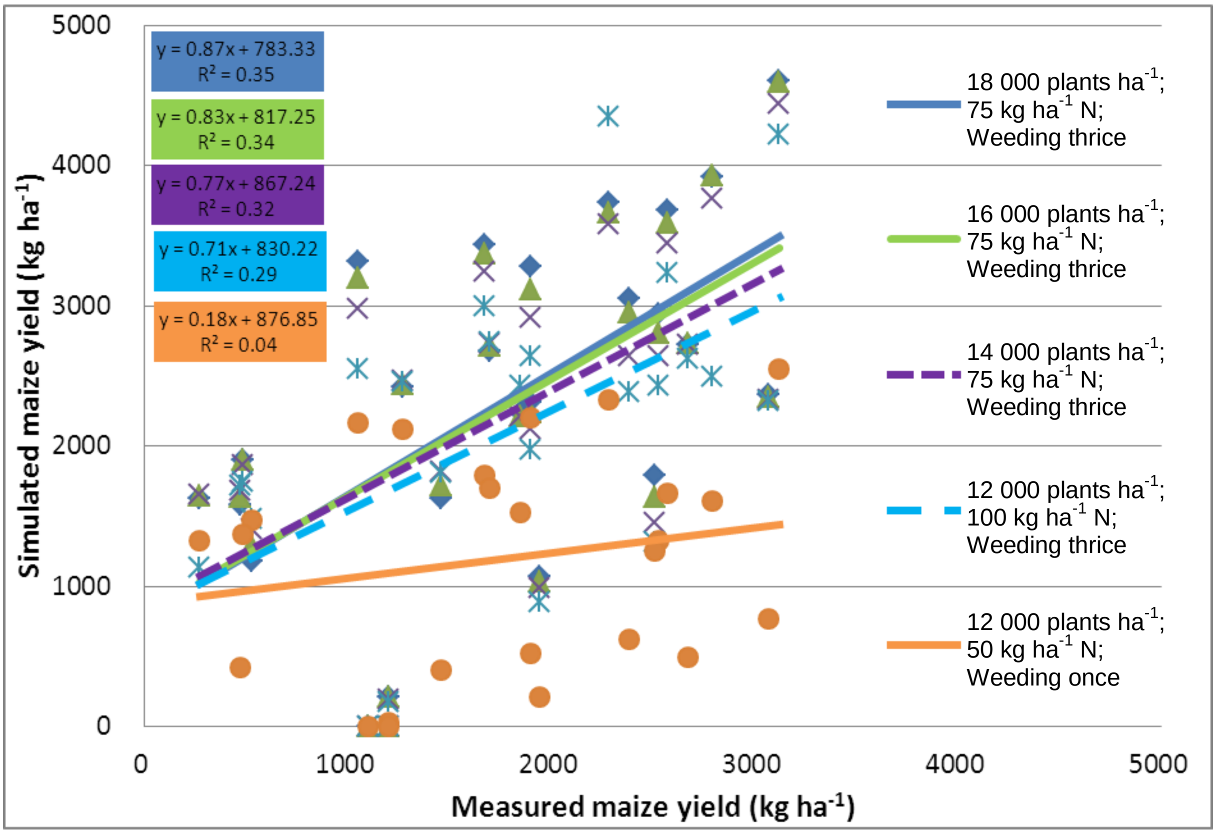


Figure 4.9: Relationship between measured and simulated maize yield for Pioneer 3237 under different plant population densities, fertiliser application rates and weeding frequencies (planted during 16-30 November).

In summary the results obtained for 1-15 November produced better correlations for both PAN 6479 and Pioneer 3237 (Figure 4.6 to Figure 4.9). The decision was therefore taken to use this planting date to simulate the maize yields which were compared with the measured ones in the next section. Figures 4.10 and 4.11 are timeline comparisons of measured and simulated maize yields under different population densities and fertiliser application rates for PAN 6479 and Pioneer 3237, respectively.

Comparison between Figures 4.10 and 4.11 showed that the model simulated the maize yields for PAN 6479 better than Pioneer 3237. The simulated maize yields for PAN 6479 followed the same trend as that of the measured maize yields except for the 1987/88, 1989/90, 1997/98 and 2002/2003 seasons. The variation in simulated and measured maize yields for Pioneer 3237 was larger than for PAN 6479. Figures 4.10 and 4.11 indicate that during the 1990/91 season, the simulated maize yield for PAN 6479 and Pioneer 3237 were 1 963 and 5 220 kg ha^{-1}, respectively, while the measured maize yield was 1 850 kg ha^{-1}. From these it is clear that the model tend to over-simulate the yield. Exceptions occurred for Pioneer 3237 during the 1984/85, 1987/88 and 1992/93 seasons when the model tend to under-simulate the yield.

The model also managed to simulate low yields during extreme climatic events like flood or drought seasons for PAN 6479. An example of this was the 1982/83 drought associated with a strong El Niño event. Figures 4.10 and 4.11 also indicated that measured yield during this event was 270 kg ha^{-1}, while for PAN 6479 yields were between 552 and 829 kg ha^{-1} and for Pioneer 3237 yields were between 978 and 1 082 kg ha^{-1}. The lowest difference between the measured and simulated maize yields was 282 and 708 kg ha^{-1}, while the greatest difference was 549 and 812 kg ha^{-1} for PAN 6479 and Pioneer 3237, respectively. The management practices for the simulated yields mentioned above involved different plant population densities with a fertiliser application rate of 100 kg ha^{-1} N and weeding frequency of 3 times for both cultivars.

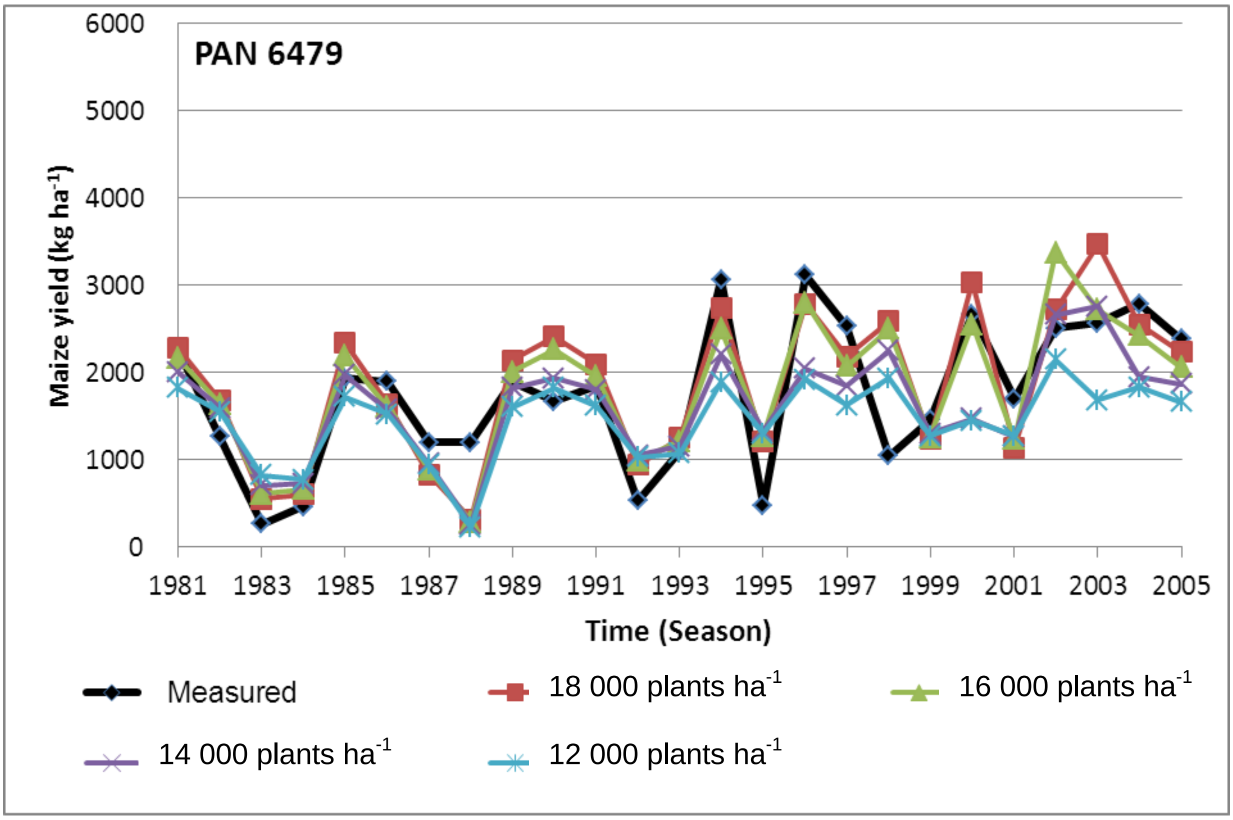


Figure 4.10: Comparison of measured and simulated maize yields for PAN 6479 under different plant population densities (planted during 1-15 November, fertiliser application rate of 100 kg ha^{-1} N and weeding thrice).

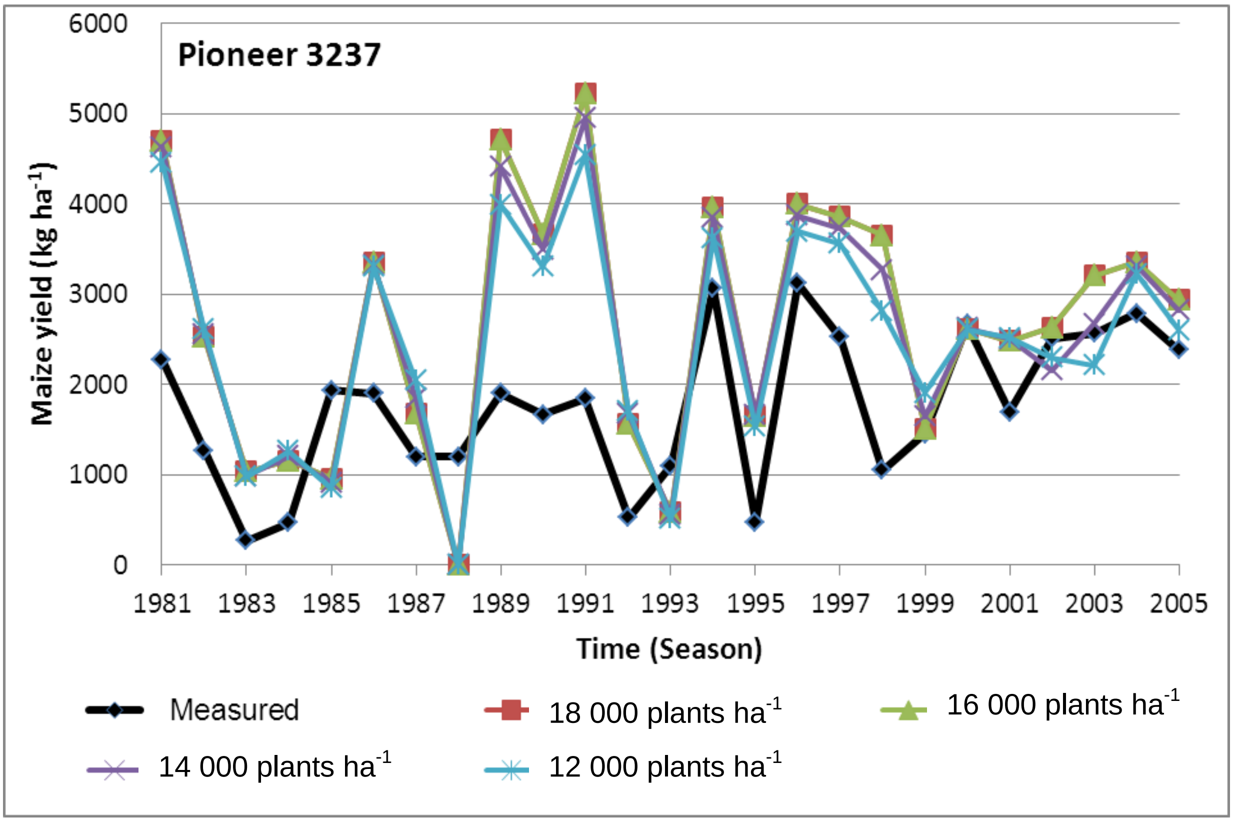


Figure 4.11: Comparison of measured and simulated maize yields for Pioneer 3237 under different plant population densities (planted during 1-15 November, fertiliser application rate of 100 kg ha^{-1} N and weeding thrice).

Another example of an extreme climatic event is the 1988 flood which was associated with a strong La Niña event. Simulated maize yields were between 228 and 318 kg ha^{-1} for PAN 6479 while total crop failure occurred for Pioneer 3237. During this flooding event, the measured maize yield was 1 200 kg ha^{-1}. In this case the model under-simulated the maize yields by more than 800 kg ha^{-1} for PAN 6479 and 1 200 kg ha^{-1} for Pioneer 3237 under different management practices. The reason for the higher difference between measured and simulated maize yields during this event could be ascribed to the fact that measured yields were averaged for the region while actual yields may have been much lower in some flooded areas. The influences of a series of recurring droughts in the 1990s (also associated with the El Niño phenomenon) are also evident in Figures 4.10 and 4.11.

Validation measures such as RMSE, ME, index of agreement (d) and modelling efficiency were used to evaluate the performance of the model under those management practices which produced simulated maize yields closer to the measured maize yields. Tables 4.1 and 4.2 illustrate the validation results obtained under different management practices for PAN 6479 and Pioneer 3237, respectively. As discussed in section 3.3, RMSE is an overall measure of model performance, while low values of RMSE indicated that the simulated maize yields were good, explaining most of the variation in the measured maize yields. For the components of RMSE (RMSEu and RMSEs), large RMSEs values showed there was a bias in the model, while RMSEs values approaching zero indicated the model performed well. The closer RMSEu to the RMSE, the better the model's performance. Under such conditions the deviations of simulated maize yield from measured maize yield are random. The index of agreement (d) measures the degree to which the model's predictions are error free. It varies between 0 (complete disagreement) and 1 (complete agreement between the measured and simulated maize yields). Modelling efficiency compares the variability between modelled maize yields with the measured maize yields, where the variability ranges from zero to one. A negative value of the modelling efficiency indicates that the modelled variability is greater than the experimental variability and therefore, the simulation is not satisfactory.

The validation results indicated that the model simulated the maize yields better for PAN 6479 than Pioneer 3237 for similar management practices (Table 4. 1 and Table 4.2). Under management practices comprised of planting during 1-15 November, a plant population density of 18 000 plants ha^{-1}, a fertiliser application rate of 75 kg ha^{-1} N and a weeding frequency of 3 times, the R^2 was 0.63 and 0.37, D-index was 0.88 and 0.61, modelling efficiency was 0.56 and -2.04 for PAN 6479 and Pioneer 3237, respectively. For PAN 6479 the set of management practices that managed to simulate the maize yields best involved planting during 1-15 November, using plant population densities of 16 000 and 18 000 plants ha^{-1}, a fertiliser application rate of 100 kg ha^{-1} N and a weeding frequency of 3 times (Table 4.1). This was indicated by a D-index of 0.89 (for both plant population densities) with a good RMSEu/RMSE of 0.90 (for 16 000 plants ha^{-1}) and 0.88 (for 18 000 plants ha^{-1}). Under these management practices simulation variability were lower than the measured variability, since the modelling efficiency was 0.61 and 0.59, respectively, while the positive sign of modelling efficiency indicated that the simulation was acceptable for PAN 6479. The management practices that corresponded to the lowest ME (14 kg ha^{-1}) involved planting during 1-15 November, a plant population density of 18 000 plants ha^{-1}, a fertiliser application rate of 100 kg ha^{-1} N and a weeding frequency of 2 times (Table 4.1).

For Pioneer 3237 (Table 4.2) the relationship between simulated and measured maize yields revealed large errors under different management practices. The largest ME of -1 171 kg ha^{-1} involved planting during 16-30 December, a plant population density of 12 000 plants ha^{-1}, a fertiliser application rate of 75 kg ha^{-1} N and a weeding frequency of 1 time (Table 4.2). The negative ME value indicated that the model overall under-simulated maize yields. In general, the results indicate that simulation of maize yields for Pioneer 3237 were not satisfactory, since the modelling efficiency under different management practices were negative. The worst set of management practices involved plant population densities of 12 000 plants ha^{-1} and a weeding once. The poor model performance will need to be addressed (using data from carefully constructed field trials to calibrate the model) before the results presented in the following sections can be used in practice to advise small-scale farmers.

Table 4.1: Validation results for APSIM using various management practices for PAN 6479

Management Practices	R^2	ME	RMSE	D-index	$\frac{RMSEs}{RMSE}$	$\frac{RMSEu}{RMSE}$	Modelling efficiency
Planted during 1-15 November; 18 000 plants ha^{-1}; 100 kg ha^{-1} N; Weeding thrice	0.66	126	577	0.89	0.48	0.88	0.59
Planted during 1-15 November; 16 000 plants ha^{-1}; 100 kg ha^{-1} N; Weeding thrice	0.63	56	516	0.89	0.43	0.90	0.61
Planted during 1-15 November; 18 000 plants ha^{-1}; 75 kg ha^{-1} N; Weeding thrice	0.62	139	547	0.88	0.42	0.91	0.56
Planted during 1-15 November; 18 000 plants ha^{-1}; 100 kg ha^{-1} N; Weeding twice	0.62	14	545	0.89	0.29	0.96	0.56
Planted during 1-15 November; 18 000 plants ha^{-1}; 75 kg ha^{-1} N; Weeding twice	0.61	19	538	0.88	0.39	0.92	0.57
Planted during 1-15 November; 12 000 plants ha^{-1}; 35 kg ha^{-1} N; Weeding once	0.17	-755	1080	0.54	0.90	0.44	-0.72
Planted during 16-30 November; 18 000 plants ha^{-1}; 75 kg ha^{-1} N; Weeding thrice	0.47	174	764	0.82	0.40	0.91	0.30
Planted during 16-30 November; 18 000 plants ha^{-1}; 100 kg ha^{-1} N; Weeding thrice	0.49	122	678	0.82	0.38	0.92	0.32
Planted during 16-30 November; 16 000 plants ha^{-1}; 75 kg ha^{-1} N; Weeding thrice	0.41	26	667	0.79	0.54	0.84	0.34
Planted during 16-30 November; 12 000 plants ha^{-1}; 35 kg ha^{-1} N; Weeding once	0.08	-595	1049	0.50	0.85	0.52	-0.62
Planted during 1-15 December; 18 000 plants ha^{-1}; 100 kg ha^{-1} N; Weeding thrice	0.37	-169	806	0.77	0.38	0.93	0.04
Planted during 1-15 December; 18 000 plants ha^{-1}; 75 kg ha^{-1} N; Weeding thrice	0.34	-159	828	0.76	0.38	0.92	-0.01
Planted during 1-15 December; 12 000 plants ha^{-1}; 50 kg ha^{-1} N; Weeding once	0.14	-761	1131	0.56	0.84	0.54	-0.89
Planted during 16-30 December; 18 000 plants ha^{-1}; 100 kg ha^{-1} N; Weeding thrice	0.24	-407	1000	0.68	0.59	0.80	-0.38
Planted during 16-30 December; 18 000 plants ha^{-1}; 100 kg ha^{-1} N; Weeding twice	0.24	-462	1016	0.67	0.64	0.77	-0.41
Planted during 16-30 December; 12 000 plants ha^{-1}; 50 kg ha^{-1} N; Weeding once	0.08	-851	1238	0.51	0.86	0.52	-1.26

Table 4.2: Validation results for APSIM using various management practices for Pioneer 3237

Management Practices	R^2	ME	RMSE	D-index	$\frac{RMSEs}{RMSE}$	$\frac{RMSEu}{RMSE}$	Modelling efficiency
Planted during 1-15 November; 18 000 plants ha^{-1}; 75 kg ha^{-1} N; Weeding thrice	0.42	999	1270	0.61	0.46	0.89	-2.04
Planted during 1-15 November; 18 000 plants ha^{-1}; 100 kg ha^{-1} N; Weeding thrice	0.37	973	1497	0.59	0.65	0.76	-2.32
Planted during 1-15 November; 16 000 plants ha^{-1}; 75 kg ha^{-1} N; Weeding thrice	0.41	960	1381	0.62	0.70	0.72	-1.81
Planted during 1-15 November; 16 000 plants ha^{-1}; 100 kg ha^{-1} N; Weeding thrice	0.37	926	1428	0.60	0.65	0.76	-2.01
Planted during 1-15 November; 12 000 plants ha^{-1}; 35 kg ha^{-1} N; Weeding once	0.07	-565	1141	0.52	0.73	0.68	-0.92
Planted during 16-30 November; 18 000 plants ha^{-1}; 75 kg ha^{-1} N; Weeding thrice	0.35	552	1117	0.68	0.50	0.86	-0.84
Planted during 16-30 November; 18 000 plants ha^{-1}; 100 kg ha^{-1} N; Weeding thrice	0.34	548	1160	0.67	0.48	0.88	-0.98
Planted during 16-30 November; 16 000 plants ha^{-1}; 75 kg ha^{-1} N; Weeding thrice	0.34	522	1097	0.68	0.49	0.87	-0.78
Planted during 16-30 November; 12 000 plants ha^{-1}; 100 kg ha^{-1} N; Weeding once	0.05	-544	1176	0.48	0.74	0.68	-1.04
Planted during 1-15 December; 18 000 plants ha^{-1}; 100 kg ha^{-1} N; Weeding thrice	0.28	-176	984	0.70	0.31	0.95	-0.43
Planted during 1-15 December; 18 000 plants ha^{-1}; 50 kg ha^{-1} N; Weeding thrice	0.28	-333	947	0.70	0.48	0.88	-0.32
Planted during 1-15 December; 12 000 plants ha^{-1}; 50 kg ha^{-1} N; Weeding once	0.07	-959	1334	0.51	0.87	0.50	-1.62
Planted during 16-30 December; 18 000 plants ha^{-1}; 50 kg ha^{-1} N; Weeding thrice	0.23	-817	1181	0.60	0.78	0.63	-1.06
Planted during 16-30 December; 16000 plants ha^{-1}; 50 kg ha^{-1} N; Weeding twice	0.21	-843	1197	0.58	0.80	0.60	-1.11
Planted during 16-30 December; 12 000 plants ha^{-1}; 75 kg ha^{-1} N; Weeding once	0.06	-1171	1483	0.37	0.91	0.42	-1.29

4.3 Analysis of simulated maize yields

4.3.1 Background

Rainfall is the single most important agro-climatic variable that determines the cropping system and overall agricultural productivity in rainfed areas (Khaliq *et al.,* 2007; Philips *et al.,* 1998; Du Plessis, 2003; Walker & Schulze, 2006). Hu and Buyanovsky (2003); Walker and Schulze (2006) confirmed that timeliness, adequacy and reliability of rainfall not only affect maize production under rainfed conditions, but is also responsible for yield variations. According to Subedi and Ma (2009) the most important management factors for achieving high maize yields were the selection of a suitable cultivar, sufficient fertiliser application rate, optimum plant population density, appropriate planting dates, and timely weeding. Selection of management decisions linked with the long-term climate conditions of various seasonal rainfall scenarios should be important in increasing maize yields (Du Plessis, 2003). With the use of APSIM simulated maize yields were obtained under various rainfall conditions and different management practices within selected quaternary catchments. The statistical program, SAS, were used to determine the contributions of predictors such as planting date, plant population density, fertiliser application rate and weeding to the yields of two maize cultivars (PAN 6479 and Pioneer 3237). A stepwise regression was employed to select those yield predictors by partial R^2 values that were statistically significant (at the 0.15 confidence level). Subsequently, optimum combinations of management practices were constructed for each possible seasonal rainfall scenario.

Readers are advised that the simulated maize yields presented in this section cannot be used in the field to advice farmers as the model’s validation was not satisfactory. However, it was deemed important to assess the influence of various management practices on the yields simulated by APSIM for the two medium growth period cultivars under different seasonal rainfall conditions.

4.3.2 Above-normal followed by above-normal (AN-AN) rainfall conditions

During AN-AN rainfall scenarios farmers may typically expect a good cropping season. Farmers should take advantage of the high rainfall totals by optimising the management practices in order to produce high maize yields. Water-logging and flooding are some of the hazards that could affect growth negatively during AN-AN rainfall conditions. In the 196 years of combined rainfall data there were 19 AN-AN seasons. The most significant yield predictors during AN-AN rainfall conditions, as determined by stepwise regression, are shown in Table 4.3.

Table 4.3: Stepwise regression for predictors of maize yield during AN-AN rainfall conditions

Cultivar	Predictor Rank	Management Practice	Partial R^2
PAN 6479	1	Planting Date	0.1613
	2	Fertiliser Application Rate	0.1297
	3	Weeding Frequency	0.1011
	4	Plant Population Density	0.0350
Pioneer 3237	1	Planting Date	0.3587
	2	Fertiliser Application Rate	0.0974
	3	Weeding Frequency	0.0693
	4	Plant Population Density	0.0055

The first yield predictor that was found to dominate the contribution to maize yields was planting date (Table 4.3) with a partial R^2 of 0.1613 for PAN 6479 and 0.3587 for Pioneer 3237. Since any combination with the other management practices will indicate the significance of choosing different planting dates, a random selection among the CDFs were made to illustrate this fact. Figure 4.12 and Figure 4.13 are CDFs of maize yields under different planting dates for PAN 6479 and Pioneer 3237, respectively.

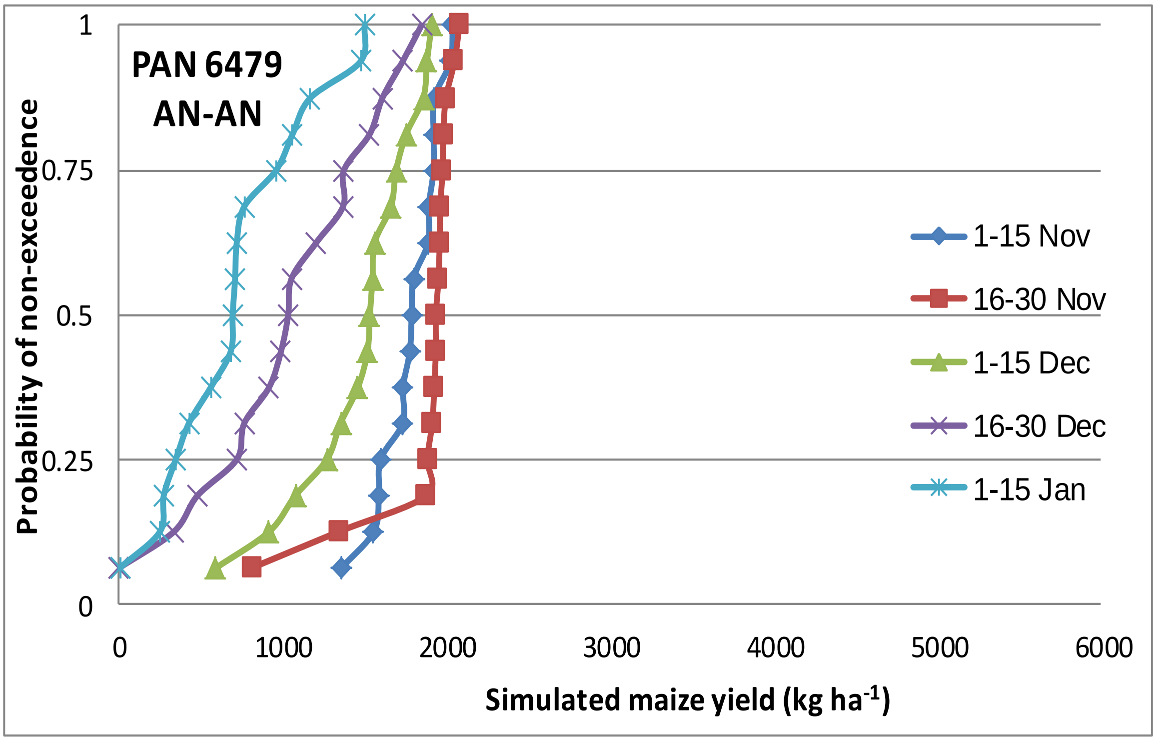


Figure 4.12: Cumulative distribution function of long-term simulated maize yields for PAN 6479 planted during different dates (using a plant population density of 12 000 plants ha^{-1}, fertiliser application rate of 35 kg ha^{-1} N and weeding once).

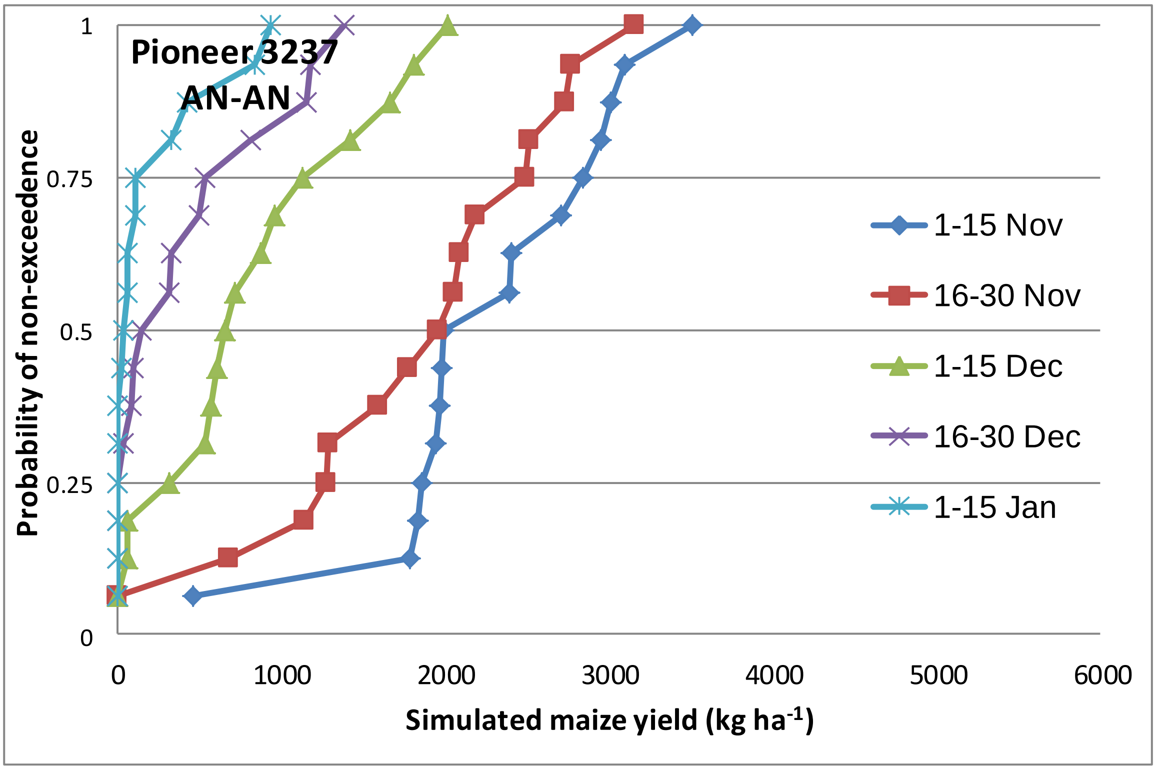


Figure 4.13: Cumulative distribution function of long-term simulated maize yields for Pioneer 3237 planted during different dates (using a plant population density of 12 000 plants ha^{-1}, fertiliser application rate of 35 kg ha^{-1} N and weeding once).

For both cultivars using earlier planting dates will result in higher yields (Figure 4.12 and Figure 4.13). For PAN 6479, the 50% probability of non-exceedence indicates that planting during 16-30 November and 1-15 January yielded 1 870 and 693 kg ha^{-1}, respectively. The farmer could therefore loose an approximated 1 243 kg ha^{-1} if the crop was planted during 1-15 January rather than 16-30 November. For Pioneer 3237, maize planted during 1-15 November and 1-15 January yielded 1 991 and 29 kg ha^{-1}, respectively, at the same probability level. Thus an additional yield of 1 962 kg ha^{-1} could be obtained by planting during 1-15 November rather than 1-15 January. At the 75% probability of non-exceedence it was evident that the maize yields planted during 1-15 November and 16-30 November were 2 848 and 2 491 kg ha^{-1}, respectively. Farmers could therefore gain an additional 357 kg ha^{-1} by planting during 1-15 November.

The second predictor that was found to contribute highly to maize yields for both cultivars was fertiliser application rate (Table 4.3), where the partial R^2 was 0.1297 and 0.0974 for PAN 6479 and Pioneer 3237, respectively. It is well known that soil fertility plays a significant role in maize production, ensuring sustained high yields. A contribution of the planting dates and fertiliser application rate to maize yields increases the partial R^2 of PAN 6479 and Pioneer 3237 to 0.2910 and 0.4561, respectively. Contributions of the combination of these two yield predictors are important, since optimum fertiliser application rate and timely sowing dates could prove beneficial during wet seasons. Simulated maize yields were obtained for various fertiliser application rates with timely planting dates (while other yield predictors were kept constant) as illustrated by Figure 4.14 and Figure 4.15 for PAN 6479 and Pioneer 3237, respectively.

Figure 4.14 shows that during AN-AN rainfall conditions optimum fertiliser application rates are required to produce high maize yields under PAN 6479. The 50% probability of non-exceedence indicated that fertiliser application rates of 50, 75 and 100 kg ha^{-1} N corresponded to yields of 2 429, 2 319 and 2 326 kg ha^{-1}, respectively. Therefore exceeding 50 kg ha^{-1} N of fertiliser would not increase the yield notably. It can also be seen that yields of 2 223 and 2 503 kg ha^{-1} correspond to applications of 35 and 50 kg ha^{-1} N at the 75% probability level. The farmer could therefore gain an additional 280 kg ha^{-1} by applying 50 kg ha^{-1} N as opposed to 35 kg ha^{-1} N.

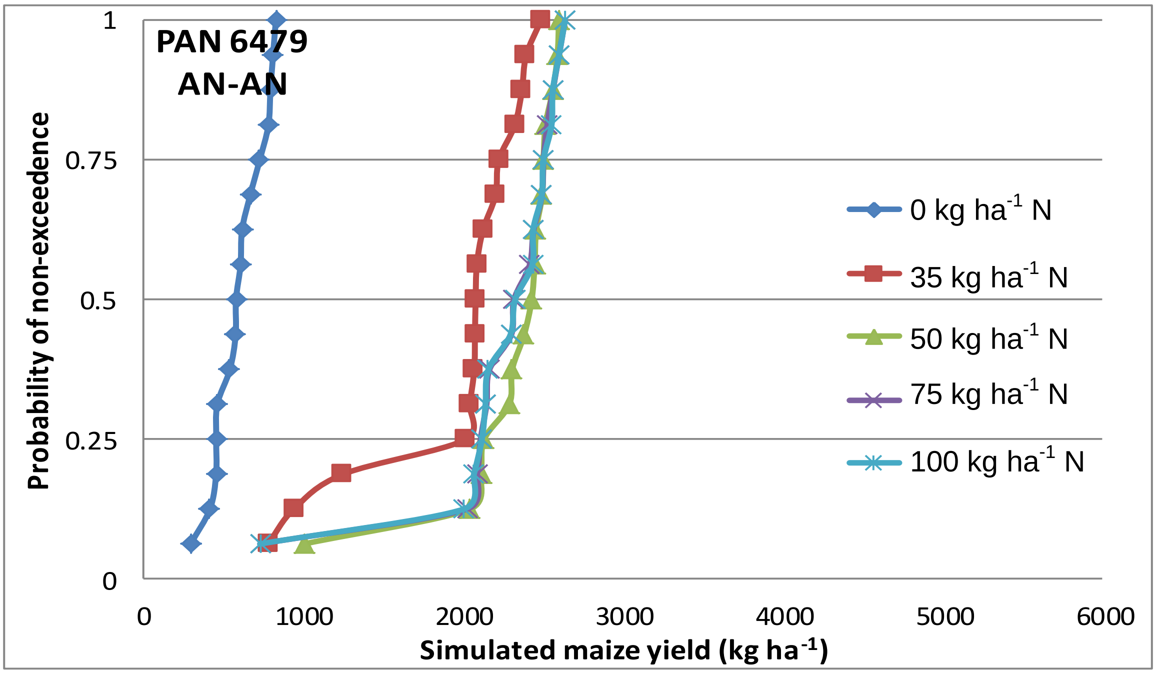


Figure 4.14: Cumulative distribution function of long-term simulated maize yields of PAN 6479 planted from 16-30 November under various fertiliser application rates (using a plant population density of 15 000 plants ha^{-1} and weeding frequency of 2).

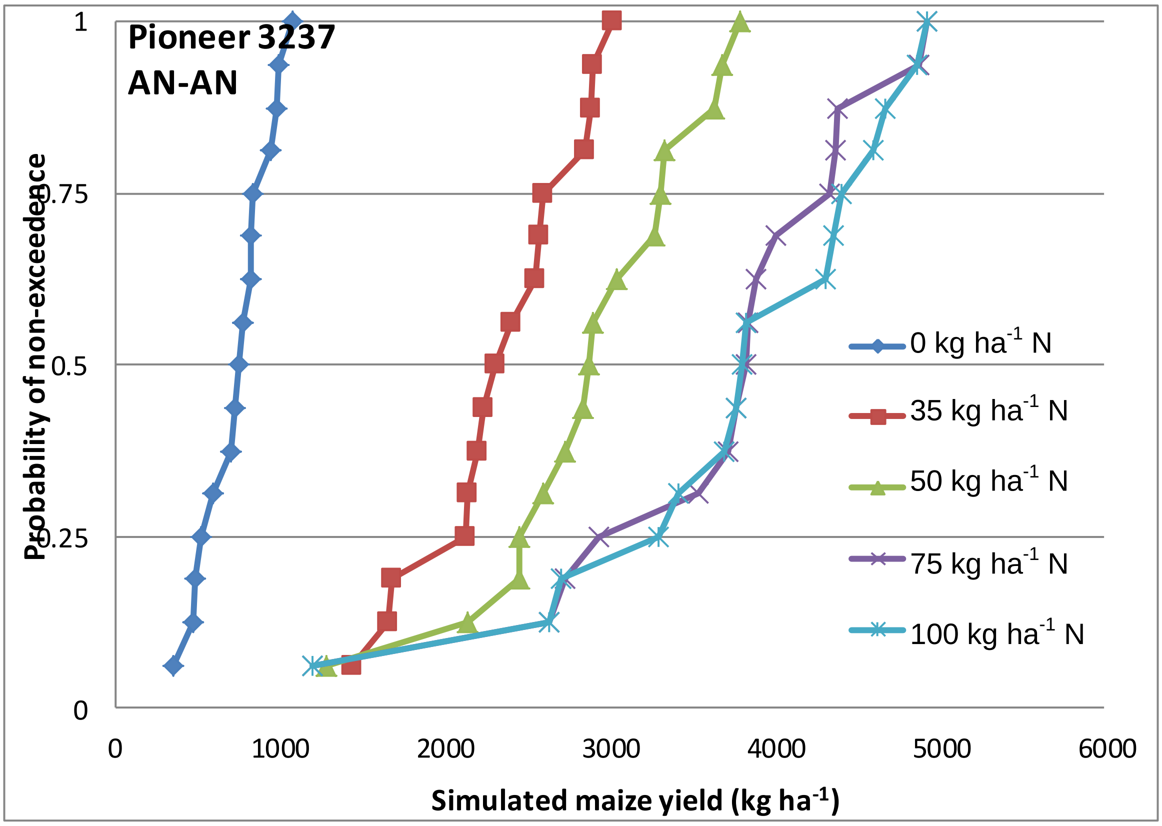


Figure 4.15: Cumulative distribution function of long-term simulated maize yields of Pioneer 3237 planted between 1-15 November under various fertiliser application rates (using a plant population density of 15 000 plants ha^{-1} and weeding frequency of 2).

For Pioneer 3237 (Figure 4.15) it was found that the maize yield under 0 and 35 kg ha^{-1} N of fertiliser application rate corresponded to 703 and 2 307 kg ha^{-1} at the 50% probability level. By simply adding 35 kg ha^{-1} N, the farmer can increase the yield by 1 604 kg ha^{-1}. At the 75% probability level fertiliser application rates of 35, 50, 75 and 100 kg ha^{-1} N corresponded to 2 597, 3 316, 4 342 and 4 414 kg ha^{-1}, respectively. The yield difference between 75 and 35 kg ha^{-1} N was 1 745 kg ha^{-1}, while the yield difference between 100 and 75 kg ha^{-1} N was just 62 kg ha^{-1}.

For both cultivars the third ranked yield predictor found to contribute significantly to maize yield was weeding frequency, with partial R^2 were 0.1101 and 0.0693 for PAN 6479 and Pioneer 3237, respectively (Table 4.3). Alam (1991) found that weeds affect the yield and quality of harvested maize heavily by competing for resources, thereby causing huge economic losses. The top three significant yield predictors contribute 0.3921 and 0.5254 to the partial R^2 for PAN 6479 and Pioneer 3237, respectively. Figures 4.16 and 4.17 illustrated the CDFs of maize yields under various weeding frequencies and planting dates with optimum fertiliser application rate and planting dates for PAN 6479 and Pioneer 3237, respectively.

At the 50% probability of non-exceedence a maize yield of 936 kg ha^{-1} will be obtained without weeding, while a yield of 2 690 kg ha^{-1} will also obtained when weeding twice for PAN 6479 (Figure 4.16). The yield difference is approximately 1 753 kg ha^{-1}. Maize yields obtained at the 75% probability of non-exceedence with 1, 2 or 3 weedings were 2 107, 2 871 or 2 889 kg ha^{-1}, respectively. Increased weeding frequency up to 2 times benefitted the grain yield of PAN 6479. For Pioneer 3237, at the 50% probability of non-exceedence 0, 2 and 3 times of weeding control corresponded to 1 414, 3 484 and 3 800 kg ha^{-1}, respectively (Figure 4.17). The yield difference between zero and 3 weeding times was 2 386 kg ha^{-1}. At the 75% probabability level maize yields of 4 064 and 4 036 kg ha^{-1} were obtained with 2 and 3 weedings, respectively.

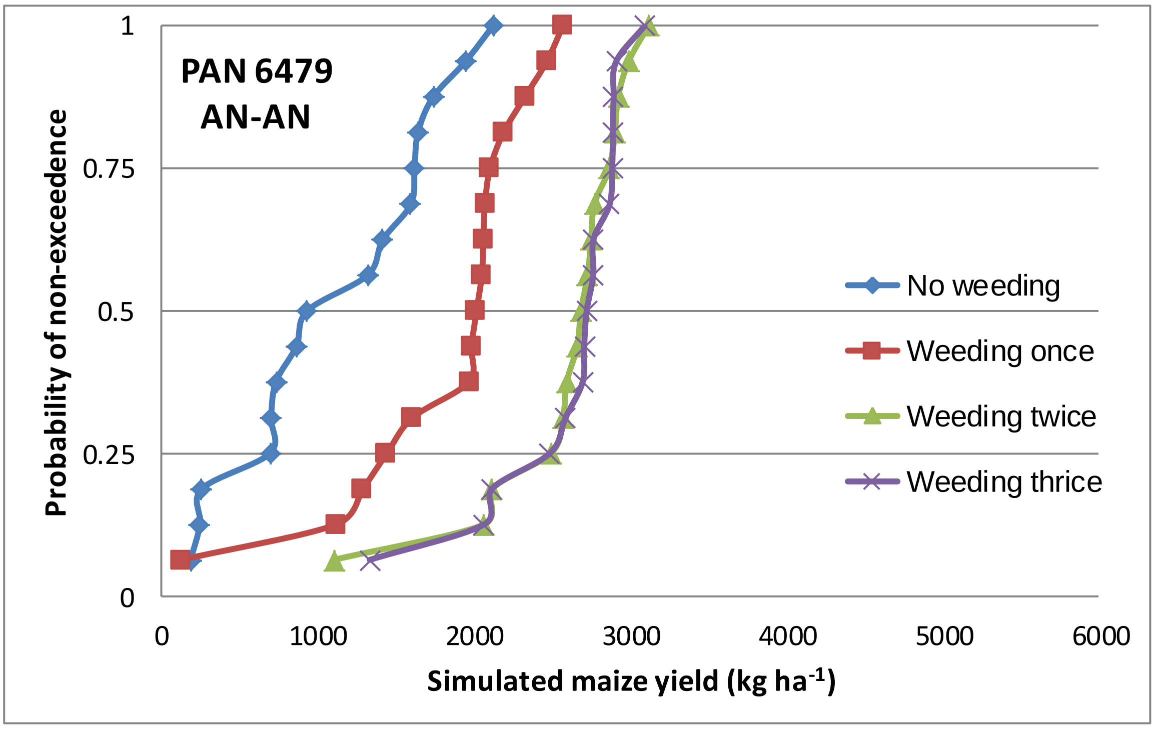


Figure 4.16: Cumulative distribution function of long-term simulated maize yields of PAN 6479 planted from 16-30 November under various weeding frequencies (using a plant population density of 18 000 plants ha^{-1} and fertiliser application rate of 50 kg ha^{-1} N).

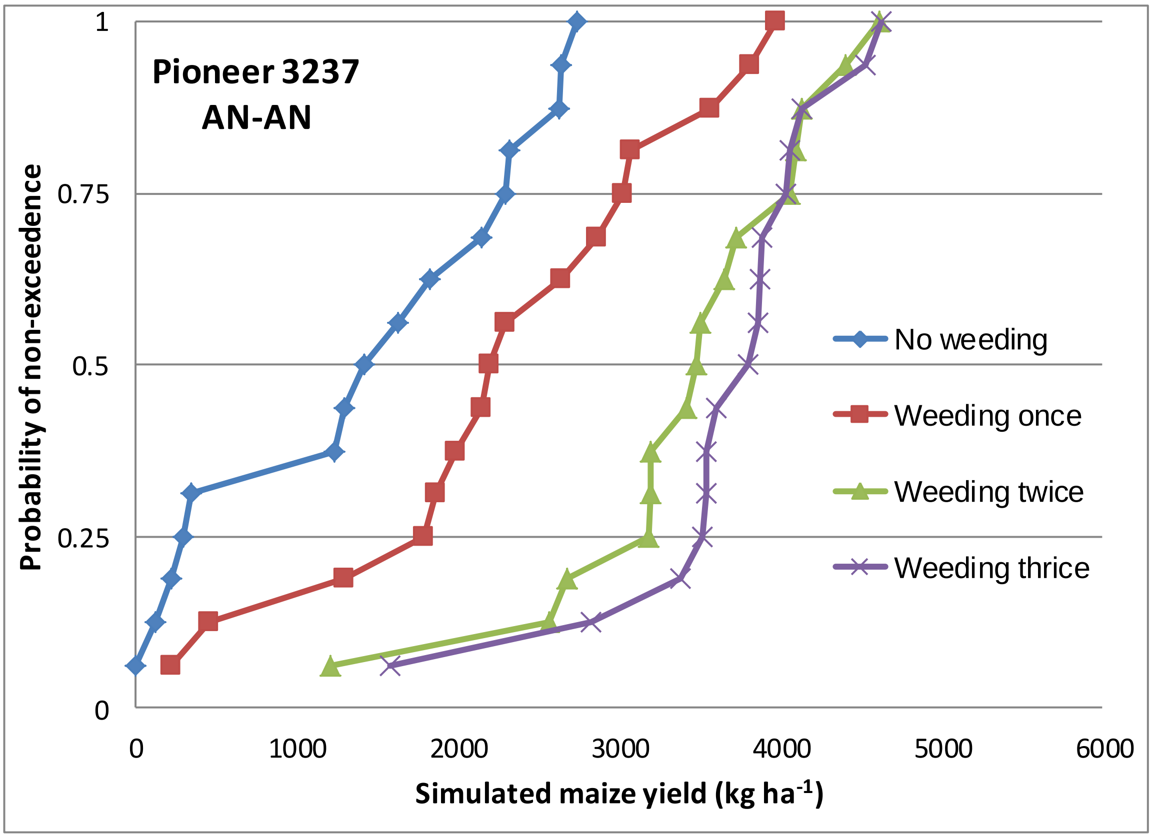


Figure 4.17: Cumulative distribution function of long-term simulated maize yields of Pioneer 3237 planted from 1-15 November under various weeding frequencies (using a plant population density of 12 000 plants ha^{-1} and fertiliser application rate of 75 kg ha^{-1} N).

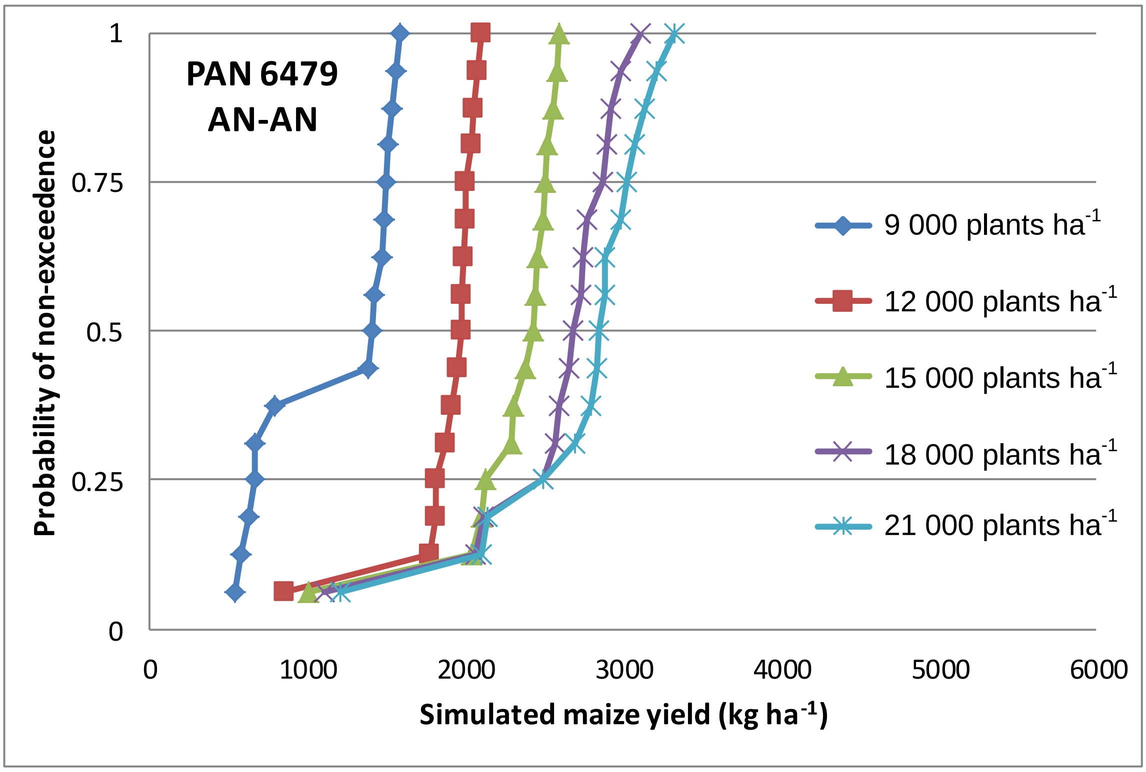


Figure 4.18: Cumulative distribution function of long-term simulated maize yields of PAN 6479 planted from 16-30 November under different plant population densities (using a fertiliser application rate of 50 kg ha^{-1} N and weeding frequency of 2).

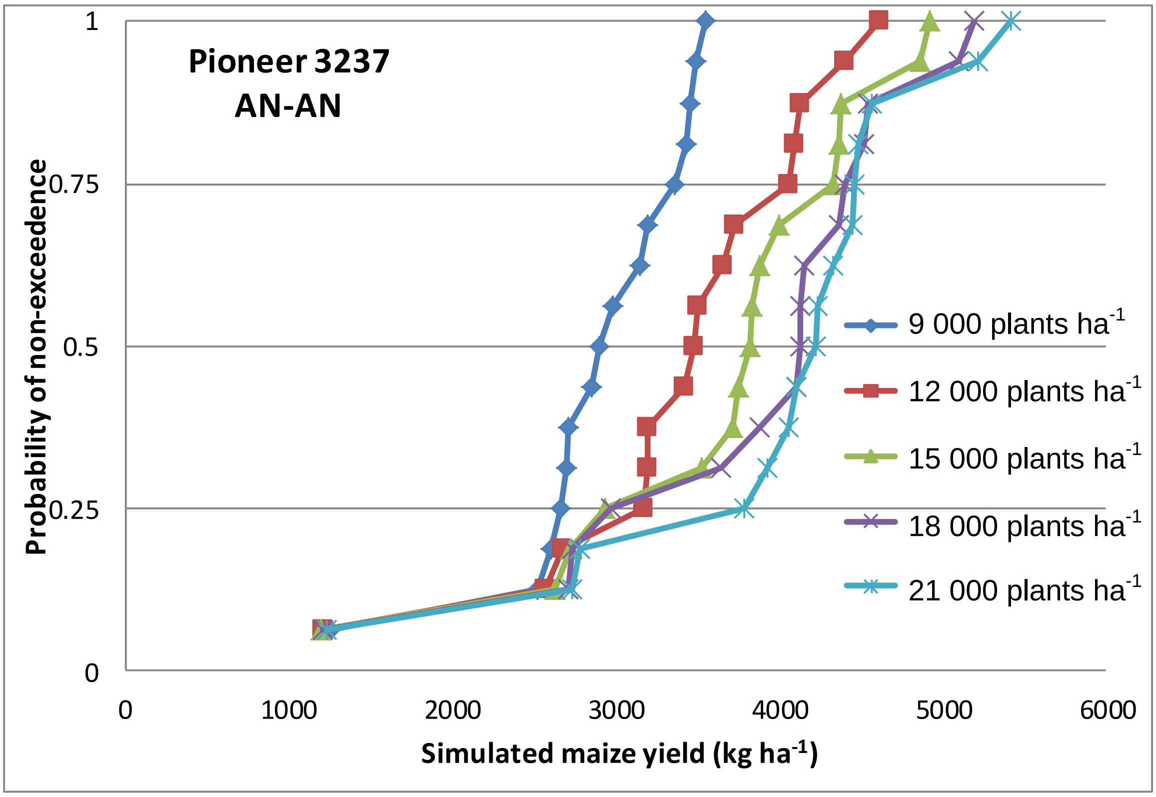


Figure 4.19: Cumulative distribution function of long-term simulated maize yields of Pioneer 3237 planted from 1-15 November under different plant population densities (using a fertiliser application rate of 75 kg ha^{-1} N and weeding twice).

The lowest ranked predictor for both cultivars was planting density, where the partial R^2 was 0.0350 and 0.0055 (Table 4.3) for PAN 6479 and Pioneer 3237, respectively. Sangoi (2001) found that maximum grain yield could be obtained under specific plant population densities for each management practice system. However, the partial R^2 for both cultivars were low compared to other yield predictors. The contribution of different plant population densities (under optimum weeding frequencies, fertiliser application rate and planting dates) to yielding for PAN 6479 and Pioneer 3237 are presented in Figures 4.18 and 4.19, respectively.

The maize yields generally increased with increasing plant population densities (Figure 4.18). At the 50% probability of non-exceedence a plant population density of 9 000, 12 000, 15 000, 18 000 and 21 000 plants ha^{-1} corresponded to maize yields of 1 412, 1 981, 2 429, 2 690 and 2 854 kg ha^{-1}, respectively. The yield difference between 9 000 and 21 000 plants ha^{-1} was 1 442 kg ha^{-1}, while the difference between 18 000 and 21 000 plants ha^{-1} was less than 200 kg ha^{-1} (194 kg ha^{-1}). Thus, plant population densities of 18 000 and 21 000 plants ha^{-1} would result in higher maize yields during AN-AN rainfall conditions for PAN 6479.

At a 50% probability of non-exceedence a plant population density of 9 000, 12 000, 15 000, 18 000 and 21 000 plants ha^{-1} corresponded to maize yields of 2 903, 3 484, 3 825, 4 135 and 4 232 kg ha^{-1}, respectively, for Pioneer 3237 (Figure 4.19). The yield difference between 9 000 and 18 000 plants ha^{-1} was 1 232 kg ha^{-1}, while the yield difference between 18 000 and 21 000 plants ha^{-1} was only 97 kg ha^{-1}.

4.3.3 Above-normal followed by near-normal (AN-NN) rainfall conditions

AN-NN rainfall scenarios are characterised by high rainfall conditions followed by normal rainfall during the second half of the cropping season. High rainfall could cause nitrogen to leach beyond rooting depth of plants. The timing of sowing dates can play a crucial role in terms of fertiliser usage, since the plants can accumulate biomass before the high rainfall start. Table 3.4 indicated that out of 196 years of combined rainfall conditions, AN-NN scenarios accounted for 21 times. Significant yield predictors of the management practices that were screened using the stepwise regression method during AN-NN rainfall conditions are summarised in Table 4.4.

Table 4.4: Stepwise regression for predictors of maize yield during AN-NN rainfall conditions

Cultivar	Predictor Rank	Management Practice	Partial R^2
PAN 6479	1	Weeding Frequency	0.1192
	2	Planting Date	0.0810
	3	Fertiliser application rate	0.0617
	4	Plant Population Density	0.0177
Pioneer 3237	1	Planting Date	0.3110
	2	Weeding Frequency	0.1330
	3	Fertiliser application rate	0.0701
	4	Plant Population Density	0.0021

The highest ranked predictor under AN-NN rainfall scenarios for PAN 6479 was weeding frequency (with a partial R^2 of 0.1192) and for Pioneer 3237 it was the planting date (with a partial R^2 of 0.3110). Since any combination with the other management practices will indicate the significance of choosing different weeding practices and planting dates, a random selection among the CDFs were made to illustrate this fact. The CDFs in Figure 4.20 and Figure 4.21 illustrate the variation of maize yields under different weeding frequencies and planting dates for PAN 6479 and Pioneer 3237, respectively.

For PAN 6479, the optimum weeding frequency (2 times) is required to produce high yields during AN-NN rainfall (Figure 4.20). The 50% probability of non-exceedence for maize yields illustrated that without weeding the yield was 414 kg ha^{-1} and a yield of 1 929 kg ha^{-1} was achieved for weeding twice. The yield difference was approximately 1 515 kg ha^{-1}. At a 75% probability of non-exceedence maize yields under 1, 2 or 3 times of weeding corresponded to 1 765, 2 492 and 2 494 kg ha^{-1}, respectively. These clearly indicate that weeding frequency of 2 times or more lead to insignificant incremental maize yields.

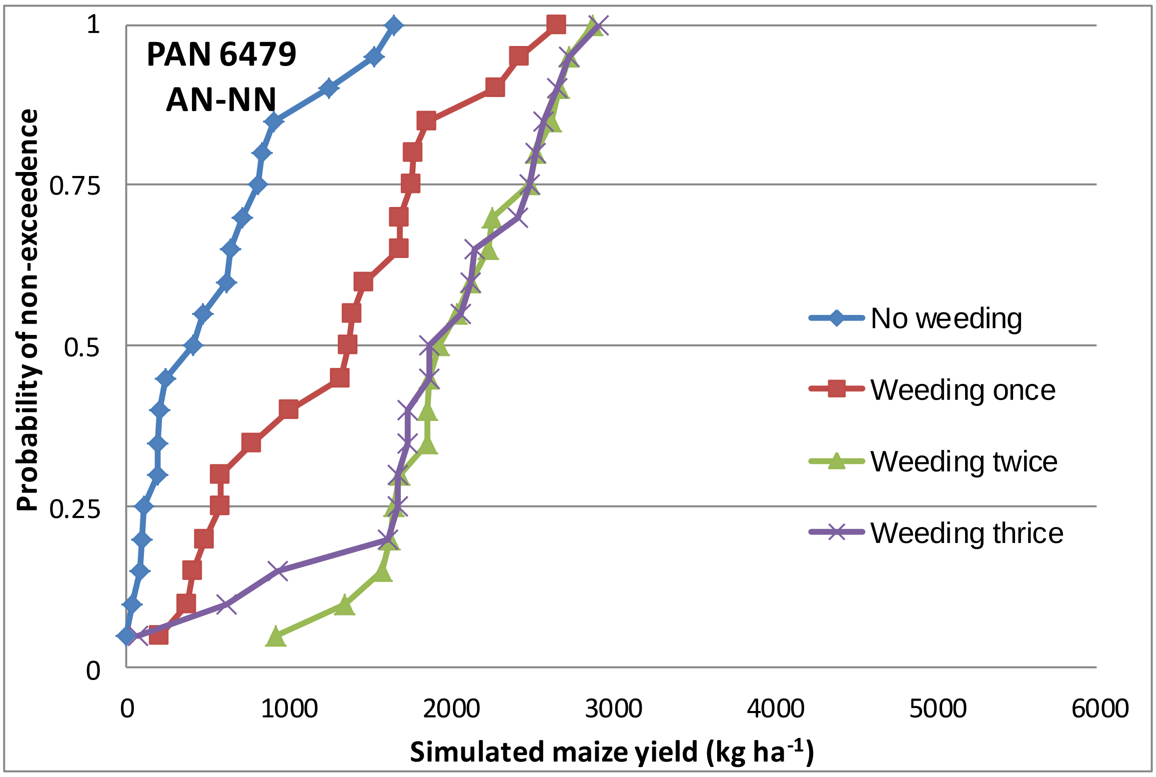


Figure 4.20: Cumulative distribution function of long-term simulated maize yields of PAN 6479 planted during 1-15 November under various weeding frequencies (using a plant population density of 18 000 plant ha^{-1} and fertiliser application rate of 50 kg ha^{-1} N).

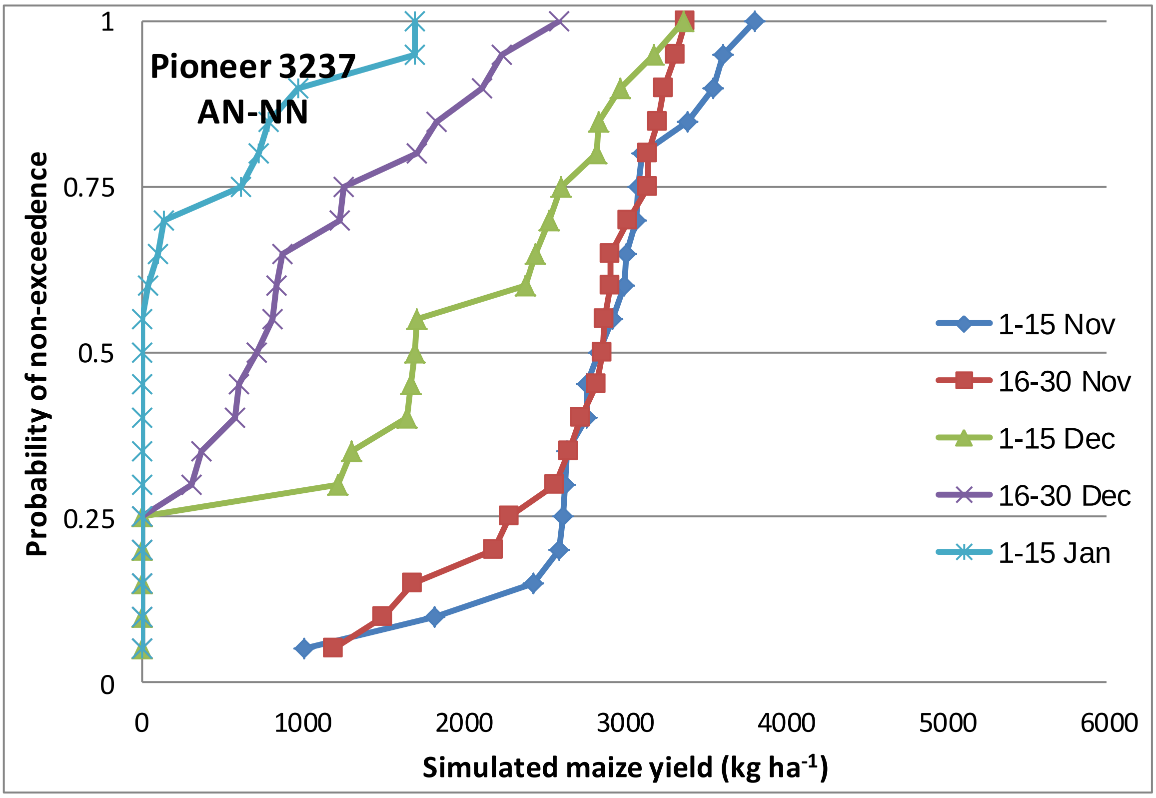


Figure 4.21: Cumulative distribution function of long-term simulated maize yields of Pioneer 3237 planted during different dates (using a plant population density of 21 000 plants ha^{-1}, fertiliser application rate of 50 kg ha^{-1} N and weeding frequency of 2).

During these seasonal rainfall conditions planting Pioneer 3237 earlier could produce higher maize yields (Figure 4.21). There is a 50% probability that the maize yield will not exceed 2 850, 2 876, 1 703, 715 and 0 kg ha^{-1} when planted during 1-15 November, 16-30 November, 1-15 December, 16-30 December and 1-15 January, respectively. These indicated that it is better to plant maize during 1-30 November than after 30 November. Farmers could run the risk of crop failure when opting to plant during in January.

The second ranked predictor found to influence maize yield for PAN 6479 was planting date, while for Pioneer 3237 it was weeding frequency. The CDFs in Figure 4.22 illustrate the variation of maize yields under different planting dates for PAN 6479, while Figure 4.23 shows the variation of Pioneer 3237 maize yields for various weeding frequencies.

During these seasonal rainfall conditions higher maize yields may be attained for PAN 6479 when planting earlier (Figure 4.22). At a 50% probability of non-exceedence planting maize during 1-15 November, 16-30 November, 1-15 December, 16-30 December and 1-15 January corresponded to yields of 1 929, 2 310, 1 593, 1 450 and 614 kg ha^{-1}, respectively. The yield difference between maize planted during 16-30 November and 1-15 November was 381 kg ha^{-1}, while the yield difference between planting maize during 16-30 November and 1-15 January was 1 669 kg ha^{-1}. This clearly shows that the best planting date to produce high maize yields during AN-NN rainfall scenarios was 16-30 November.

For Pioneer 3237, the maize yields increased with weeding frequency during AN-NN rainfall conditions (Figure 4.23). The 25% probability of non-exceedence for maize yields without weeding and weeding thrice were 565 and 3 160 kg ha^{-1}, respectively. The famer could obtain more than 2 500 kg ha^{-1} when opting not to perform weeding as opposed to weeding twice. The yield difference between weeding twice and thrice at the 25% and 50% probability of non-exceedence were 495 and 471 kg ha^{-1}, respectively.

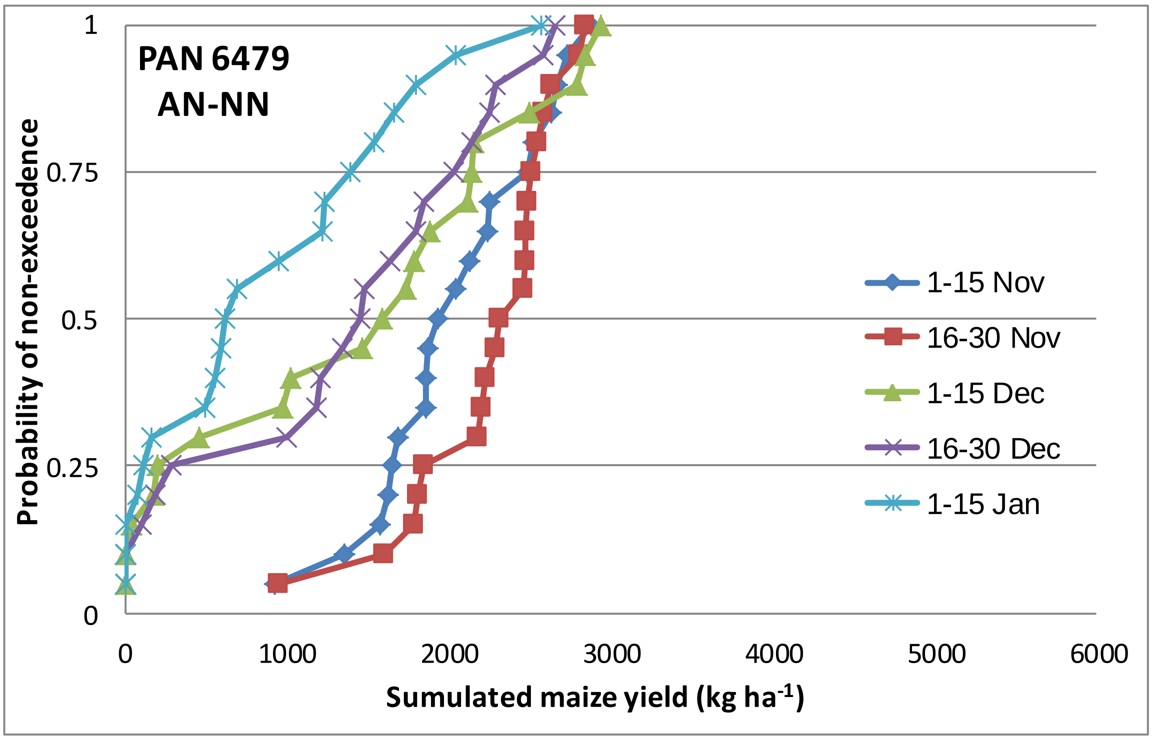


Figure 4.22: Cumulative distribution function of long-term simulated maize yields for PAN 6479 planted during different dates (using a plant population density of 18 000 plants ha^{-1}, fertiliser application rate of 50 kg ha^{-1} N and weeding twice).

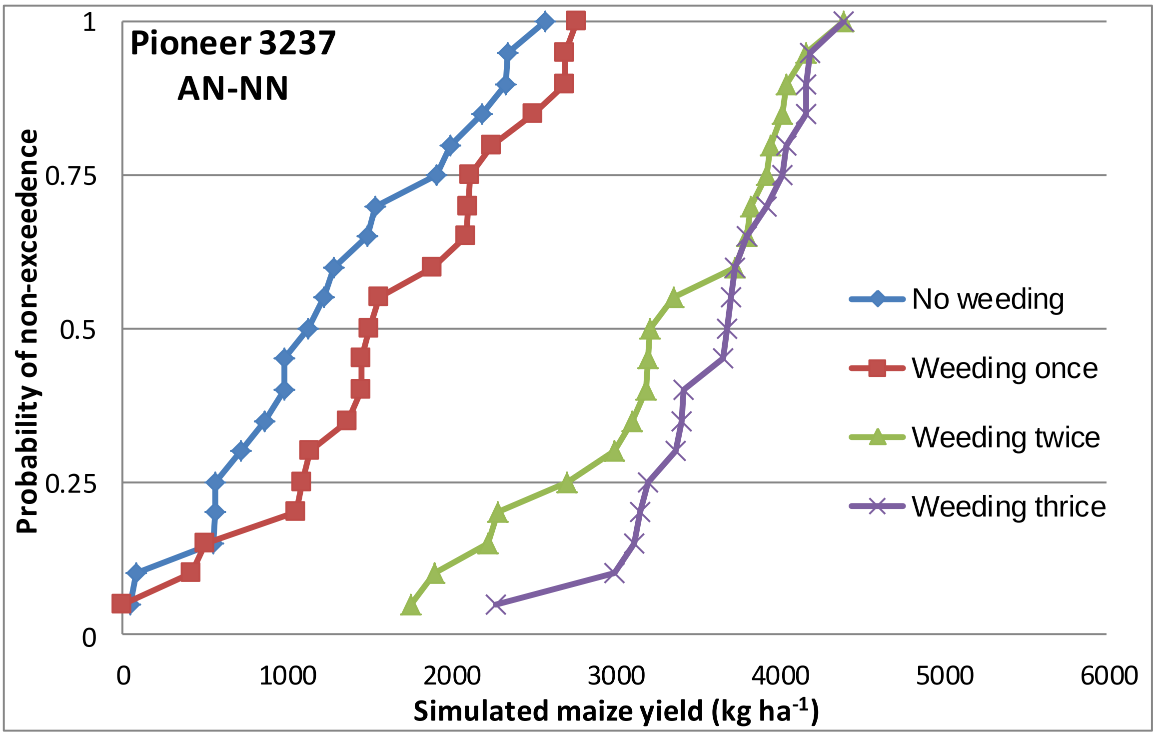


Figure 4.23: Cumulative distribution function of long-term simulated maize yields for Pioneer 3237 planted during 1-15 November under various weeding frequencies (using a plant population density of 12 000 plant ha^{-1} and a fertiliser application rate of 75 kg ha^{-1} N).

The third and fourth significant predictors found to contribute to maize yields were fertiliser application rate and plant population density for both cultivars (Table 4.4). The contribution of different fertiliser application rates and plant population densities on maize yield in terms of combined partial R^2 was 0.0794 and 0.0722 for PAN 6479 and Pioneer 3237, respectively. For PAN 6479, the fertiliser application rates found to contribute the most to maize yield were 35 and 50 kg ha^{-1} N (not shown), while the highest yielding plant population densities were 18 000 and 21 000 plants ha^{-1} (not shown). For Pioneer 3237, the fertiliser application rates that contributed most to maize yields were 50 and 75 kg ha^{-1} N, while the plant population densities were 9 000, 12 000 and 15 000 plants ha^{-1} (not shown).

4.3.4 Above-normal followed by below-normal (AN-BN) rainfall conditions

AN-BN rainfall conditions are characterised by high amounts of rainfall at the beginning of the season, followed by below normal rainfall later in the season. Crops may experience wet conditions or even flooding during the early growth stages and adverse dry conditions especially during reproductive phase. In the 196 years of combined rainfall data there were 27 AN-BN seasons. Significant yield predictors were screened using the stepwise regression method and the results are summarised in Table 4.5.

Table 4.5: Stepwise regression for predictors of maize yield during AN-BN rainfall conditions

Cultivar	Predictor Rank	Management Practice	Partial R^2
PAN 6479	1	Weeding Frequency	0.1242
	2	Planting Date	0.0853
	3	Fertiliser Application Rate	0.0347
	4	Plant Population Density	0.0036
Pioneer 3237	1	Planting Date	0.2152
	2	Weeding Frequency	0.1129
	3	Fertiliser Application Rate	0.0381

The dominant predictors were weeding frequency for PAN 6479 and planting date for Pioneer 3237, with a partial R^2 of 0.1242 and 0.2152 (Table 4.5), respectively. Since any combination with other management practices will indicate the significance of choosing different weeding frequencies and planting dates, a random selection among the CDFs were made to illustrate this fact. The CDFs in Figure 4.24 and Figure 4.25 illustrate the variation of maize yields under different weeding frequencies and planting dates for PAN 6479 and Pioneer 3237, respectively.

During AN-BN rainfall conditions, planting PAN 6479 the required optimum weeding frequency (2 times) for the production of the highest yield (Figure 4.24). At a 50% probability of non-exceedence maize yields without weeding and weeding thrice were 324 and 1 330 kg ha^{-1}, respectively. The yield difference was approximately 1 007 kg ha^{-1}. There was a 75% probability that the maize yields would not exceed 1122, 1 631 and 1 714 kg ha^{-1}, respectively, when the farmer opted to weed 1, 2 or 3 times. This clearly indicated that weeding thrice would lead less yield increment as compared to weeding twice.

Maize yields for Pioneer 3237 decreased as the planting date shifted later into the season (Figure 4.25). Maize planted during 1-15 November, 16-30 November, 1-15 December, 16-30 December and 1-15 January related to yields of 2 095, 1 860, 1 267, 143 and 0 kg ha^{-1}, respectively at the 50% probability level. The yield difference between planting during 1-15 November and 16-30 November was 335kg ha^{-1}, while the yield difference between 1-15 November and 16-30 December was 1 952 kg ha^{-1}. Farmers could therefore lose an approximate 2 095 kg ha^{-1} when opting to plant during 1-15 January as opposed to 1-15 November. Again it is best to use early planting dates (1-15 November and 16-30 November), since using late planting date (1-15 January) could result in crop failure.

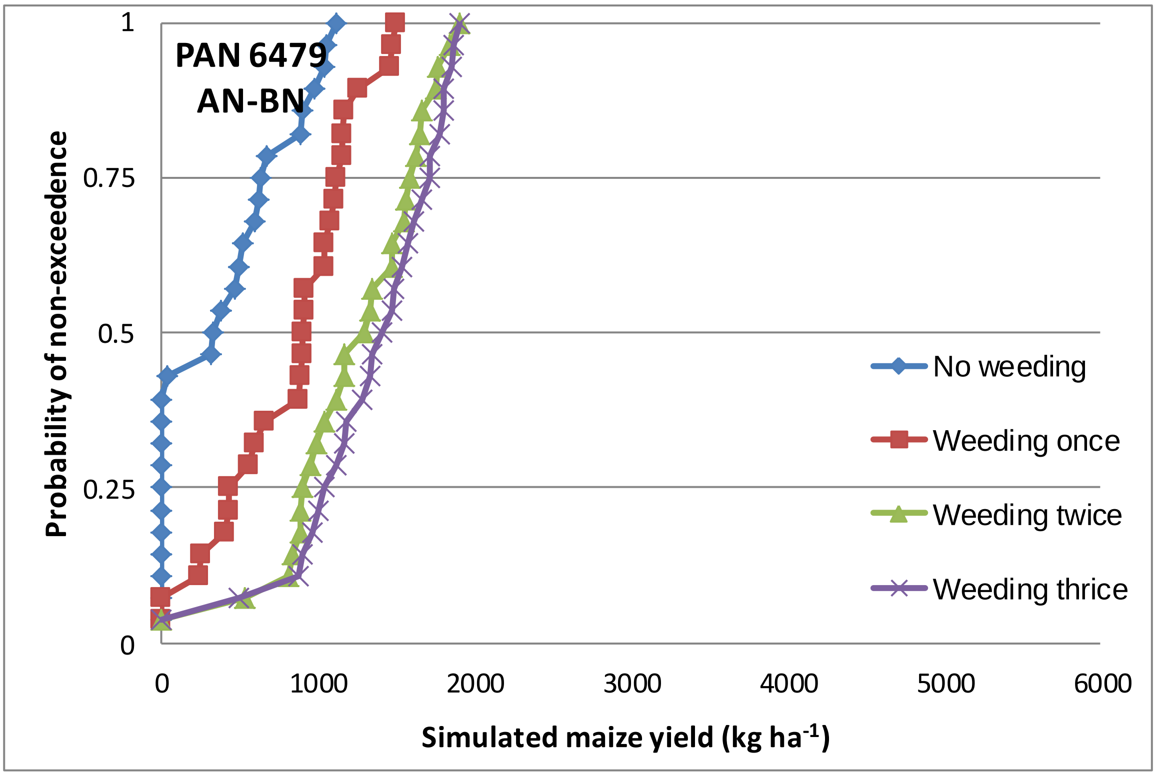


Figure 4.24: Cumulative distribution function of long-term simulated maize yields for PAN 6479 planted during 1-15 November under various weeding frequencies (using a plant population density of 12 000 plants ha^{-1} and fertiliser application rate of 50 kg ha^{-1} N).

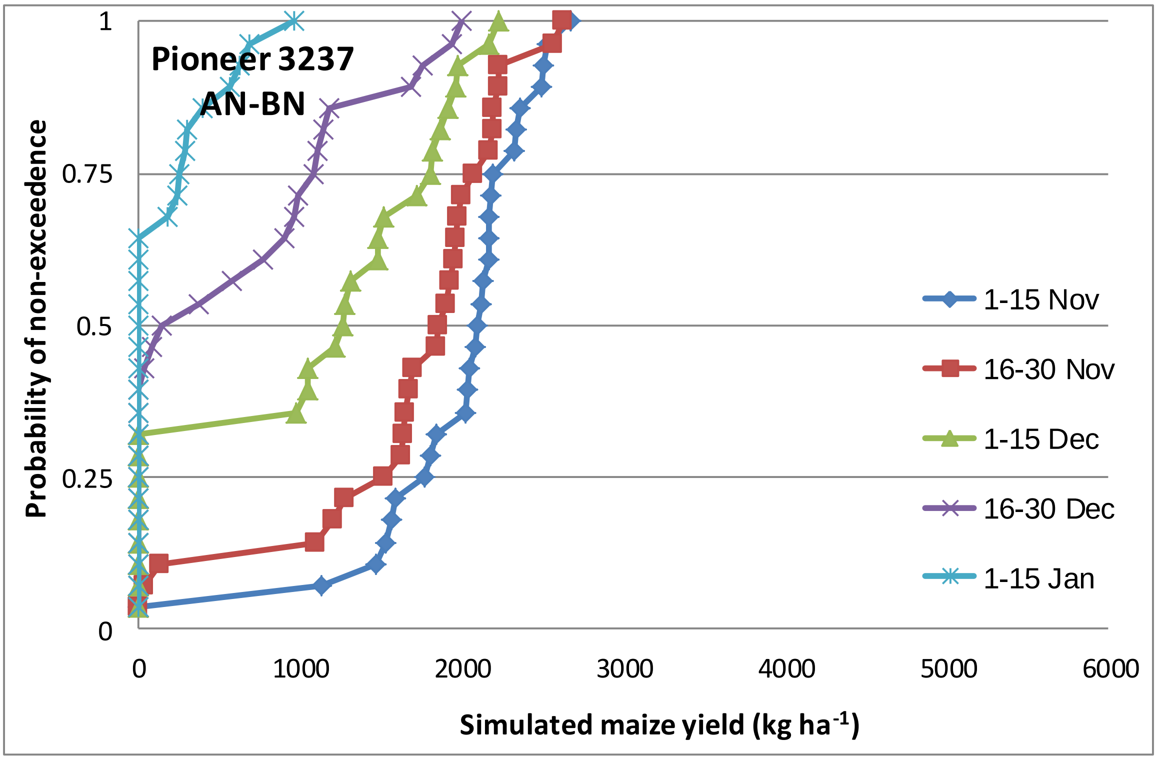


Figure 4.25: Cumulative distribution function of long-term simulated maize yields of Pioneer 3237 planted over different dates (using a plant population density of 9 000 plants ha^{-1}, fertiliser application rate of 35 kg ha^{-1} N and weeding twice).

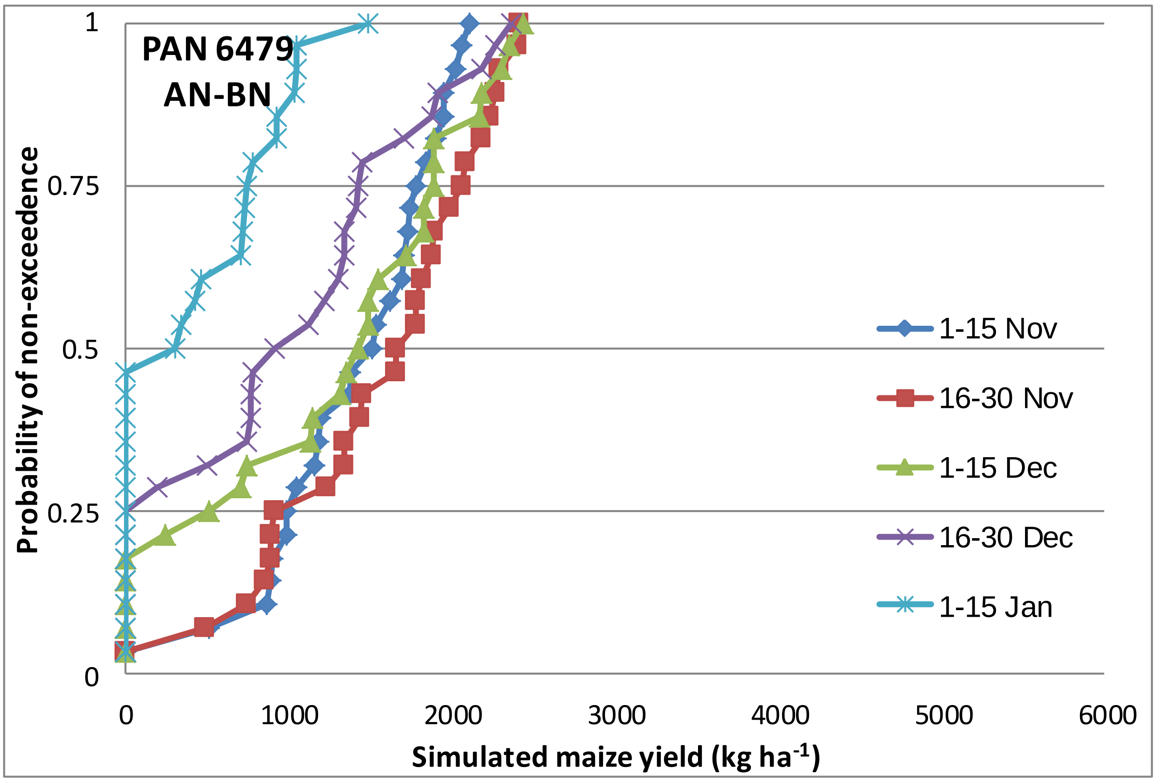


Figure 4.26: Cumulative distribution function of long-term simulated maize yields for PAN 6479 planted during different dates (using a plant population density of 15 000 plants ha^{-1}, fertiliser application rate of 35 kg ha^{-1} N and weeding twice).

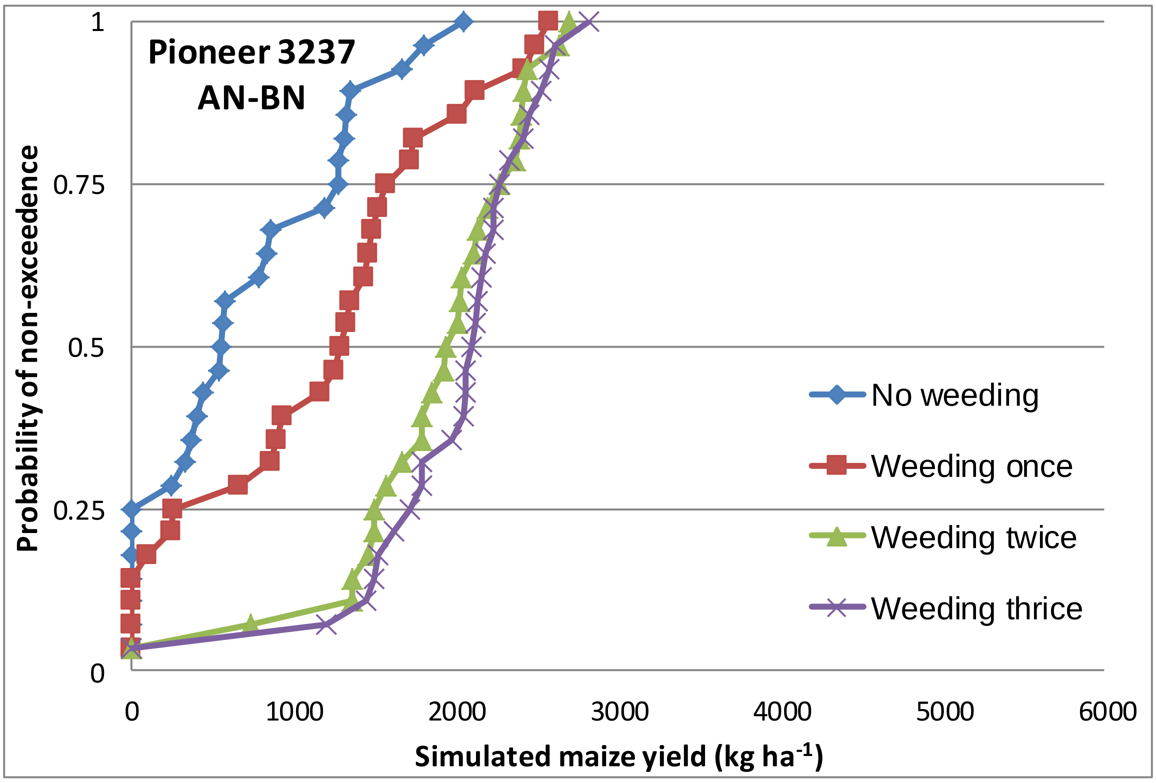


Figure 4.27: Cumulative distribution function of long-term simulated maize yields for Pioneer 3237 planted during 1-15 November under various weeding frequencies (using a plant population density of 12 000 plants ha^{-1} and fertiliser application rate of 35 kg ha^{-1} N).

The second highest predictor set that were found to influence the contribution to maize yield was planting date for PAN 6479 and weeding frequency for Pioneer 3237. The contribution of different planting dates to PAN 6479 and weeding frequencies to Pioneer 3237 were indicated by a partial R^2 of 0.0853 and 0.1129, respectively (Table 4.5). For both cultivars, the timing of planting and frequency of weeding control are crucial. The CDFs in Figure 4.26 and Figure 4.27 illustrate the variation of maize yields under different planting dates and weeding frequencies for PAN 6479 and Pioneer 3237, respectively.

There was a 50% probability that the maize yield would not exceed 1 510, 1 660, 1 429, 914 and 308 kg ha^{-1} when planted during 1-15 November, 16-30 November, 1-15 December, 16-30 December and 1-15 January, respectively (Figure 4.26). Farmers could obtain an additional 1 352 kg ha^{-1} when opting to plant during 16-30 November as opposed to 1-15 January. The 50% probability of non-exceedence for maize yields indicated that without weeding the yield was a mere 550 kg ha^{-1}, and increased to 1 944 kg ha^{-1} when weeding twice (Figure 4.27). At a 75% probability of non-exceedence, the farmer could only gain a meagre 3 kg ha^{-1} when opting to weed thrice (2 266 kg ha^{-1}) as opposed to twice (2 263 kg ha^{-1}) (Figure 4.27). This clearly shows that the weeding frequency required to produce high maize yields during AN-BN rainfall conditions was 2 times.

The third and fourth ranked predictors for PAN 6479 were fertiliser application rate and plant population density. For Pioneer 3237 only fertiliser application rate contributed significantly to maize yield (Table 4.5). The contribution fertiliser application rates and plant population densities to maize yield in terms of combined partial R^2 was 0.0383 for PAN 6479, while for Pioneer 3237 the fertiliser application rates contribution in terms of partial R^2 was 0.0381. For PAN 6479, the fertiliser application rate found to contribute highly to maize yields were 35 kg ha^{-1} N, while the plant population densities were 9 000, 12 000 and 15 000 plants ha^{-1} (not shown). For Pioneer 3237, the fertiliser application rates found to contribute highly to maize yields were 35 and 50 kg ha^{-1} N, while the plant population density was 9 000 plants ha^{-1} (not shown).

4.3.5 Near-normal followed by above-normal (NN-AN) rainfall conditions

NN-AN rainfall scenarios are characterised by average amounts of rainfall at the beginning of the growth season, followed by high rainfall later in the season. The rainfall conditions normally results in enough soil water during the early growth stages, while later the plants may benefit from the high rainfall. Farmers could use these rainfall conditions to optimise fertiliser application rates, plant population densities, weeding frequencies and planting dates to increase maize yields. Table 3.4 indicate that 21 of 196 combined seasons were NN-AN scenarios. Significant yield predictors during NN-AN rainfall conditions are summarised in Table 4.6.

Table 4.6: Stepwise regression for predictors of maize yield during NN-AN rainfall conditions

Cultivar	Predictor Rank	Management Practice	Partial R^2
PAN 6479	1	Planting Date	0.1426
	2	Fertiliser Application Rate	0.0877
	3	Weeding Frequency	0.0822
	4	Plant Population Density	0.0380
Pioneer 3237	1	Planting Date	0.2883
	2	Fertiliser Application Rate	0.0991
	3	Weeding Frequency	0.0761
	4	Plant Population Density	0.0078

Results obtained from the stepwise regression showed that the highest ranked yield predictor for both cultivars was planting date. The contributions of planting dates to maize yields were 0.14 and 0.29 (partial R^2) for PAN 6479 and Pioneer 3237, respectively (Table 4.6). Since any combination with the other management practices will indicate the significance of choosing different planting dates, a random selection among the CDFs were made to illustrate this fact. The CDFs in Figure 4.28 and Figure 4.29 illustrate the variation of maize yields under different planting dates for PAN 6479 and Pioneer 3237, respectively.

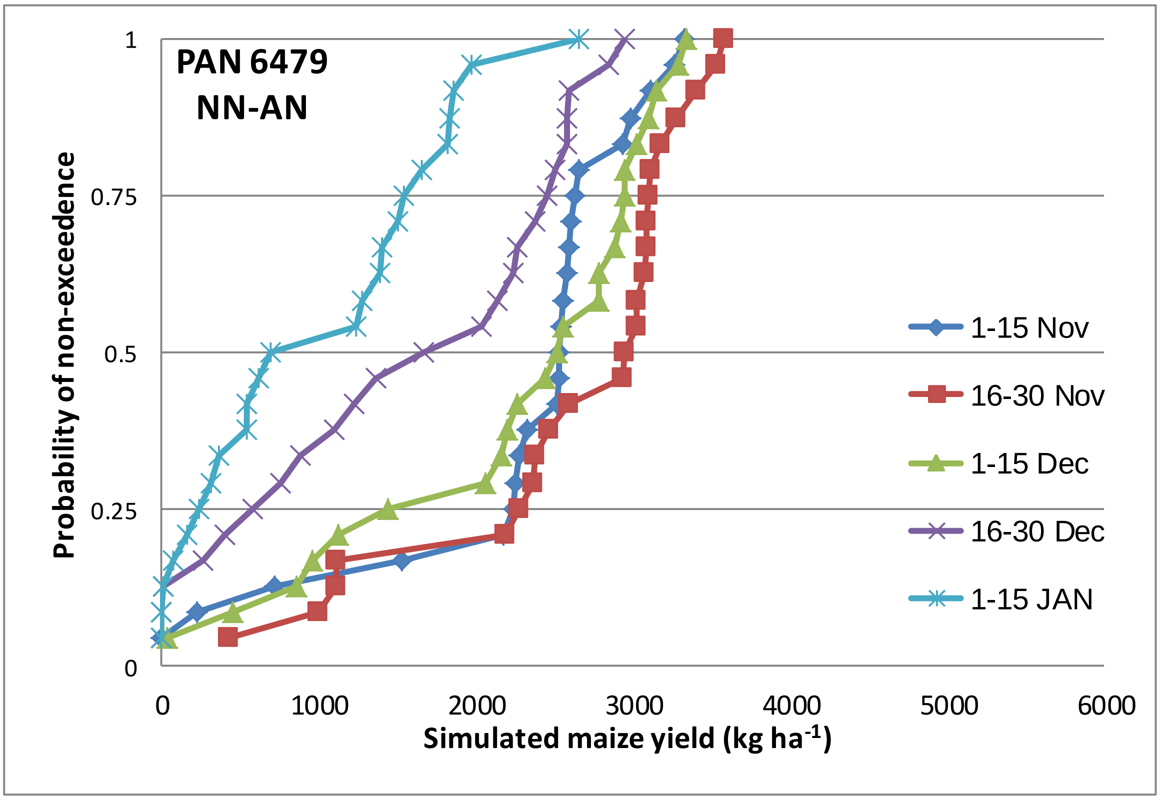


Figure 4.28: Cumulative distribution function of long-term simulated maize yields for PAN 6479 planted during different dates (using a plant population density of 21 000 plants ha^{-1}, fertiliser application rate of 50 kg ha^{-1} N and weeding thrice).

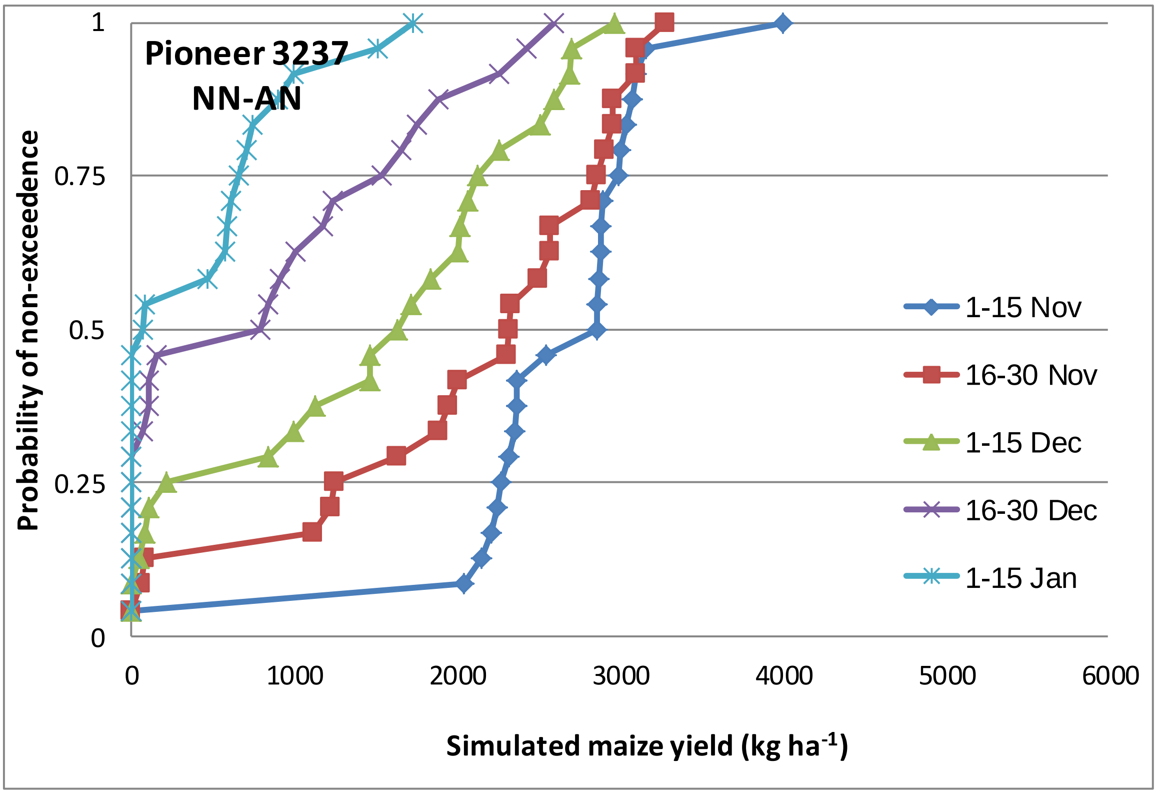


Figure 4.29: Cumulative distribution function of long-term simulated maize yields for Pioneer 3237 planted during different dates (using a plant population density of 12 000 plants ha^{-1}, fertiliser application rate of 50 kg ha^{-1} N and weeding thrice).

For PAN 6479, planting date could be delayed to late November (Figure 4.28). Maize planted during 1-15 November, 16-30 November, 1-15 December, 16-30 December and 1-15 January corresponded to yields of 2 534, 2 955, 2 524, 1 664 and 693 kg ha^{-1}, respectively at the 50% probability level. The yield difference between planting during 16-30 November and 1-15 November was 421 kg ha^{-1}, while the yield difference between planting during 16-30 November and 16-30 December was 1 291 kg ha^{-1}.

The yields of Pioneer 3237 decreased as the planting date shifted progressively later into the season (Figure 4.29). At a 50% probability of non-exceedence maize planted during 1-15 November, 1-15 December and 1-15 January corresponded to yields of 2 865, 1 634 and 76 kg ha^{-1}, respectively. Farmers could thus obtain 1 231 kg ha^{-1} more when opting to plant during 1-15 November as opposed to 1-15 December, and run the risk of losing 2 789 kg ha^{-1} when opting to plant during 1-15 January as opposed to 1-15 November.

The second highest ranked predictor found to influence maize yields during NN-AN rainfall conditions for both cultivars was fertiliser application rate, with a partial R^2 of 0.0877 and 0.0991 for PAN 6479 and Pioneer 3237, respectively (Table 4.6). The CDFs in Figure 4.30 and Figure 4.31 illustrate the variation of maize yields under different fertiliser application rates given the best planting dates for PAN 6479 and Pioneer 3237, respectively.

During NN-AN rainfall conditions, the 50% probability of non-exceedence indicated that without fertilisers the yield was 727 kg ha^{-1}, while at 50 kg ha^{-1} N the yield was 2 671 kg ha^{-1} for PAN 6479 (Figure 4.30). The yield difference indicated that the farmer could lose an approximate 1 944 kg ha^{-1} when opting not to apply any fertiliser as opposed to 50 kg ha^{-1} N of fertiliser. For Pioneer 3237, the maize yield increased with incremental application rate of fertiliser (N) (Figure 4.31). There was only a small yield difference between maize produced applying 75 and 100 kg ha^{-1} N.

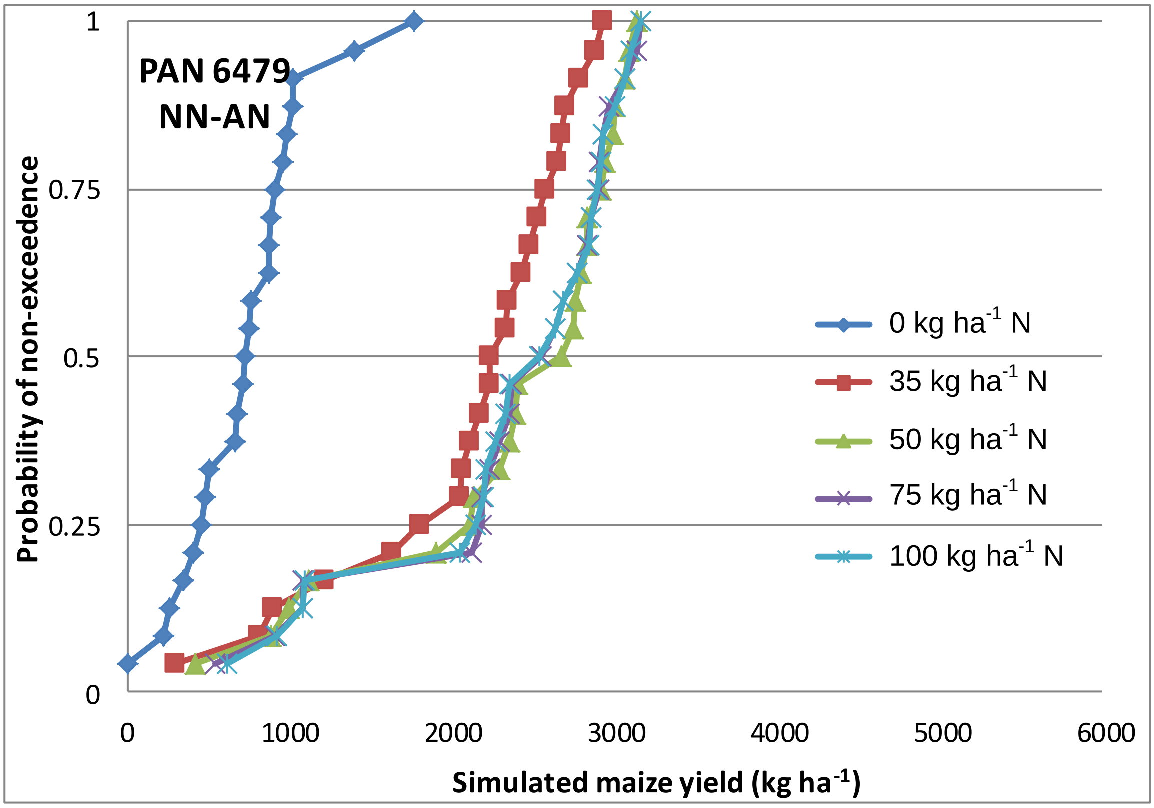


Figure 4.30: Cumulative distribution function of long-term simulated maize yields for PAN 6479 planted during 16-30 November under various fertiliser application rates (using a plant population density of 18 000 plants ha^{-1} and weeding twice).

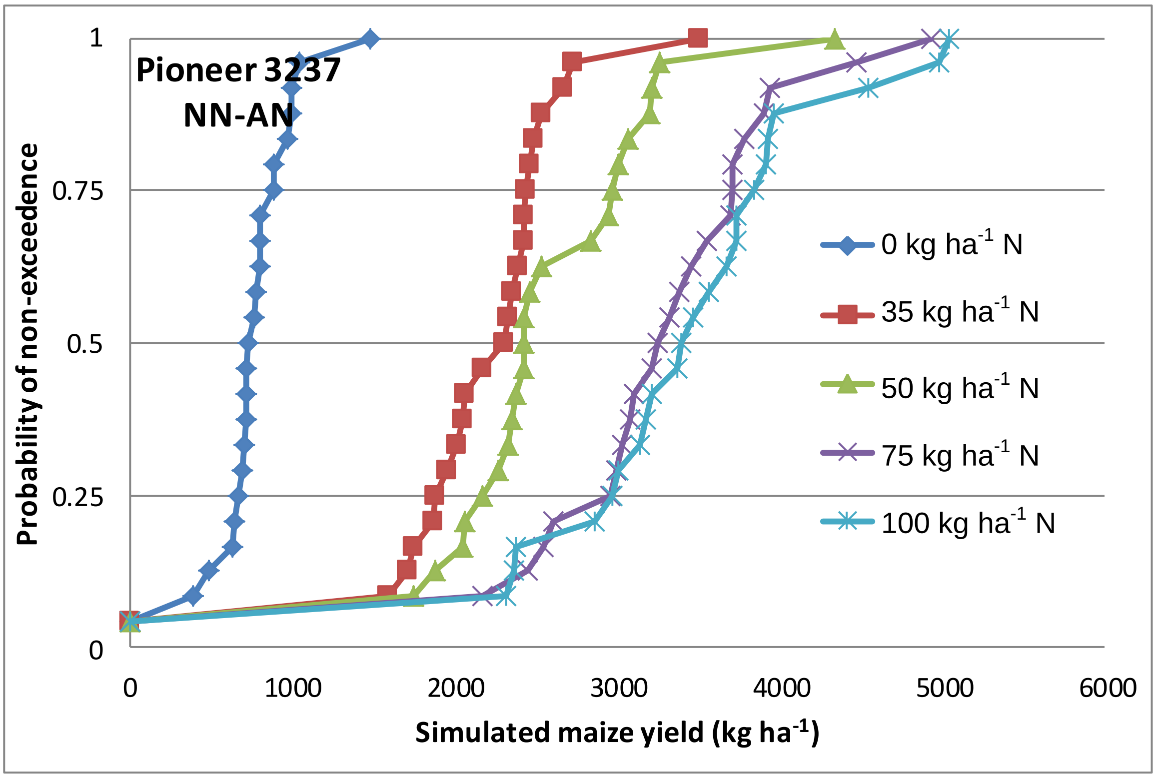


Figure 4.31: Cumulative distribution function of long-term simulated maize yields for Pioneer 3237 planted during 1-15 November under various fertiliser application rates (using a plant population density of 15 000 plants ha^{-1} and weeding twice).

For both cultivars, the third and fourth ranked predictors were weeding frequency and plant population density, respectively, with the combined R^2 of 0.012 for PAN 6479 and 0.084 for Pioneer 3237 (Table 4.6). For PAN 6479, a weeding frequency was contributed stronger to maize yield will be 1 and 2 times, followed by a plant population densities of 15 000, 18 000 and 21 000 plants ha^{-1} (not shown). For Pioneer 3237, weeding twice or thrice and using a plant population density of 9 000, 12 000 and 18 000 plants ha^{-1} performed best (not shown).

4.3.6 Near-normal followed by near-normal (NN-NN) rainfall conditions

NN-NN rainfall conditions are characterised by average amounts of rainfall throughout the cropping season. In the 196 years of combined rainfall data there were 28 NN-NN seasons, this contributed the highest rainfall scenarios occurred in Modder River catchment. The most significant yield predictors during NN-NN rainfall conditions, as determined by stepwise regression are shown in Table 4.7.

Table 4.7: Stepwise regression for predictors of maize yield during NN-NN rainfall conditions

Cultivar	Predictor Rank	Management Practice	Partial R^2
PAN 6479	1	Weeding Frequency	0.0917
	2	Fertiliser Application Rate	0.0698
	3	Planting Date	0.0579
	4	Plant Population Density	0.0146
Pioneer 3237	1	Planting Date	0.1796
	2	Weeding Frequency	0.0647
	3	Fertiliser Application Rate	0.0632
	4	Plant Population Density	0.0025

Dominating predictors for PAN 6479 and Pioneer 3237 were weeding frequency and planting dates, respectively. The contribution of weeding frequencies and different planting dates to variation of maize yields in terms of partial R^2 were 0.0917 and 0.1796 for PAN 6479 and Pioneer 3237, respectively (Table 4.7). Weeding frequency plays an important role in reducing the presence of weeds, since weeds affect the quality and yields of the maize by competing for resources.

Since any combination with the other management practices will indicate the significance of choosing different weeding frequencies and planting dates, a random selection among the CDFs were made to illustrate this fact. The CDFs in Figures 4.32 and 4.33 illustrate the variation of maize yields under different weeding frequencies and planting dates for PAN 6479 and Pioneer 3237, respectively.

Weeding twice during NN-NN rainfall conditions would produce the highest yields for PAN 6479, while non-incremental yields under weeding thrice results in water loss due to disturbance of the soil (Figure 4.32). At a 50% probability of non-exceedence level a yield of 542 kg ha^{-1} was obtained without weeding, while a yield of 2 124 kg ha^{-1} was obtained when weeding twice. Farmers could thus lose an approximate 1 572 kg ha^{-1} with no weeding as opposed to weeding twice.

During these seasonal rainfall conditions maize yields decreased as the planting date shifted later into the growing season for Pioneer 3237 (Figure 4.33). At the 50% probability of non-exceedence maize planted during 1-15 November, 16-30 November, 1-15 December, 16-30 December and 1-15 January yielded 2 334, 1 822, 1 137, 150 and 0 kg ha^{-1}, respectively. The yield difference between planting during 1-15 November and 16-30 December was 2 184 kg ha^{-1}. Planting Pioneer 3237 after 15 December would result in crop failure.

The second ranked predictors found to influence maize yield were fertiliser application rate for PAN 6479, where the partial R^2 was 0.0698 , while for Pioneer 3237 the second yield predictor was weeding frequency with a partial R^2 of 0.0667 (Table 4.7). The CDFs in Figure 4.34 illustrate the variation of maize yields under different fertiliser application rates for PAN 6479 (under optimum weeding frequency), while Figure 4.35 shows the same for weeding frequencies for Pioneer 3237 (under optimum planting dates).

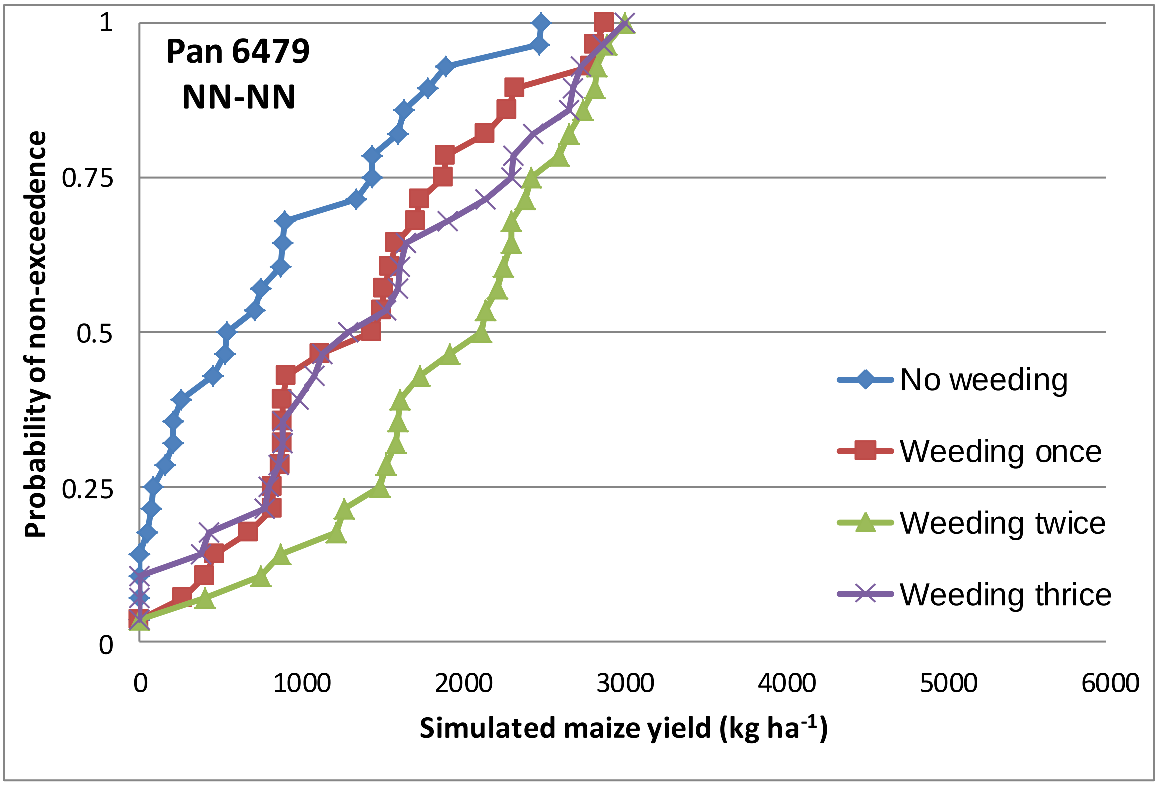


Figure 4.32: Cumulative distribution function of long-term simulated maize yields for PAN 6479 planted during 1-15 November under different weeding frequencies (using a plant population density of 18 000 plant ha^{-1} and fertiliser application rate of 50 kg ha^{-1} N).

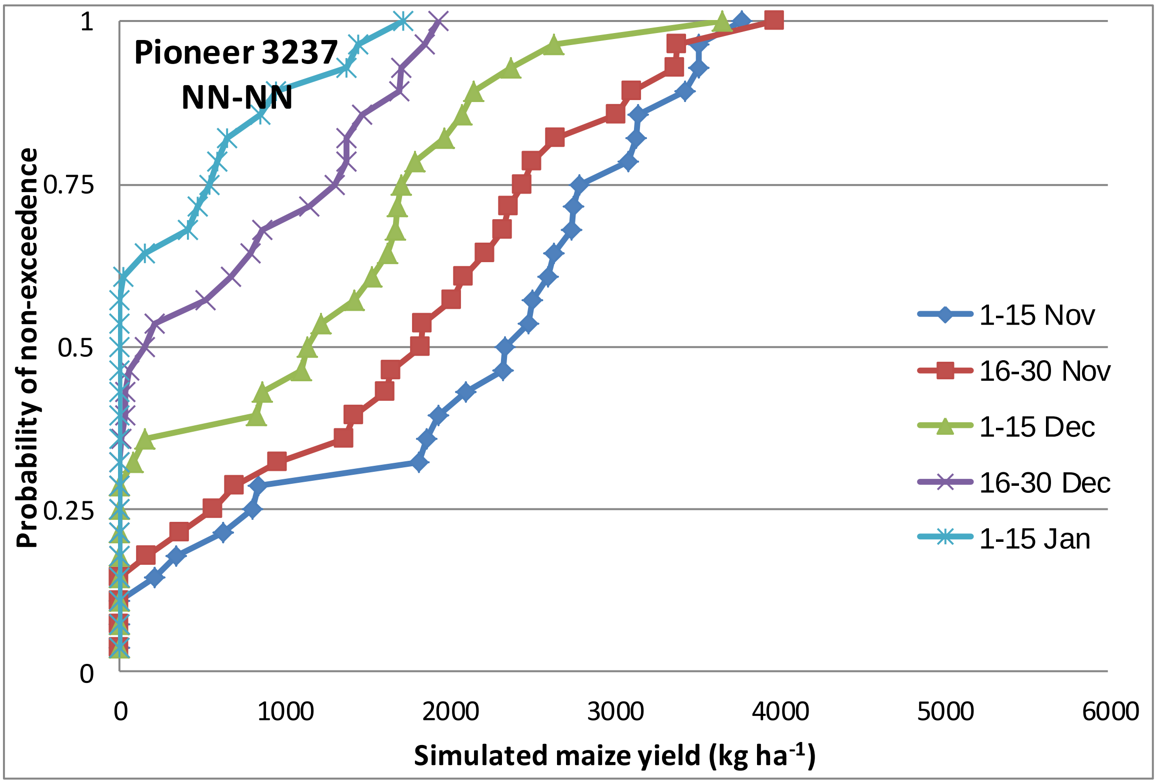


Figure 4.33: Cumulative distribution function of long-term simulated maize yields for Pioneer 3237 planted during different planting dates (using a plant population density of 12 000 plants ha^{-1}, fertiliser application rate of 50 kg ha^{-1} N and weeding twice).

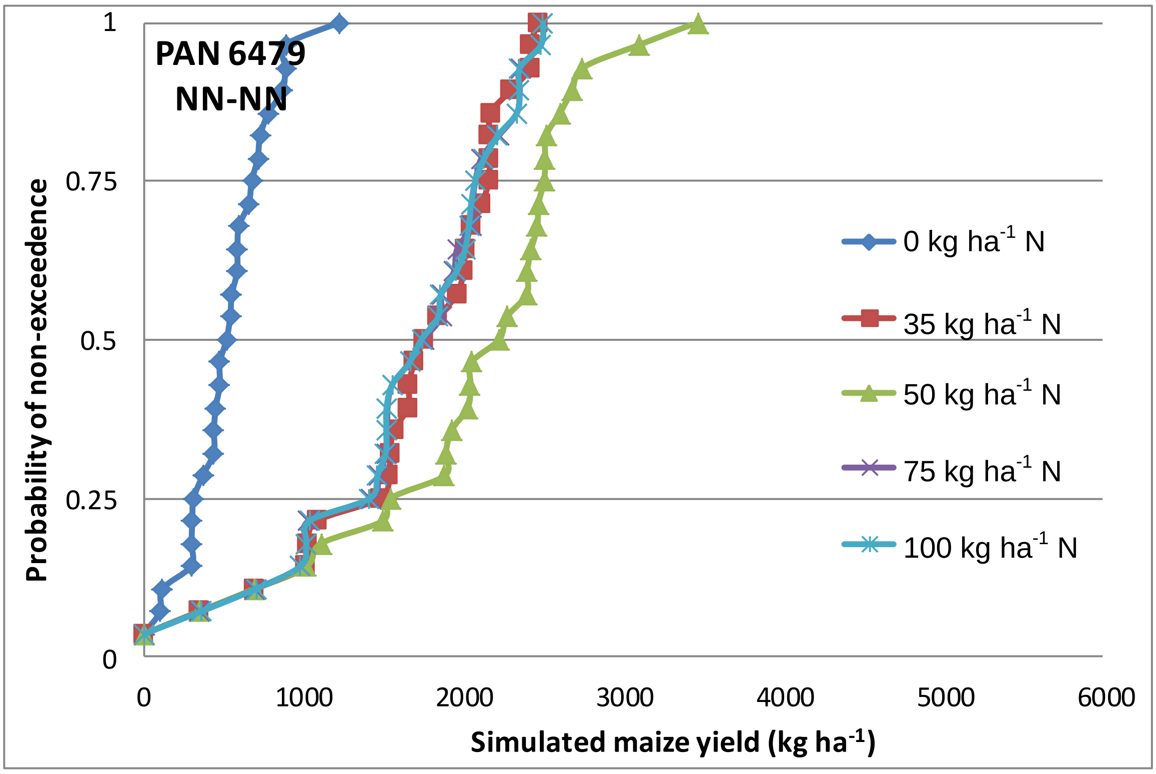


Figure 4.34: Cumulative distribution function of long-term simulated maize yields for PAN 6479 planted during 1-15 November under various fertiliser application rates (using a plant population density of 15 000 plants ha^{-1} and weeding twice).

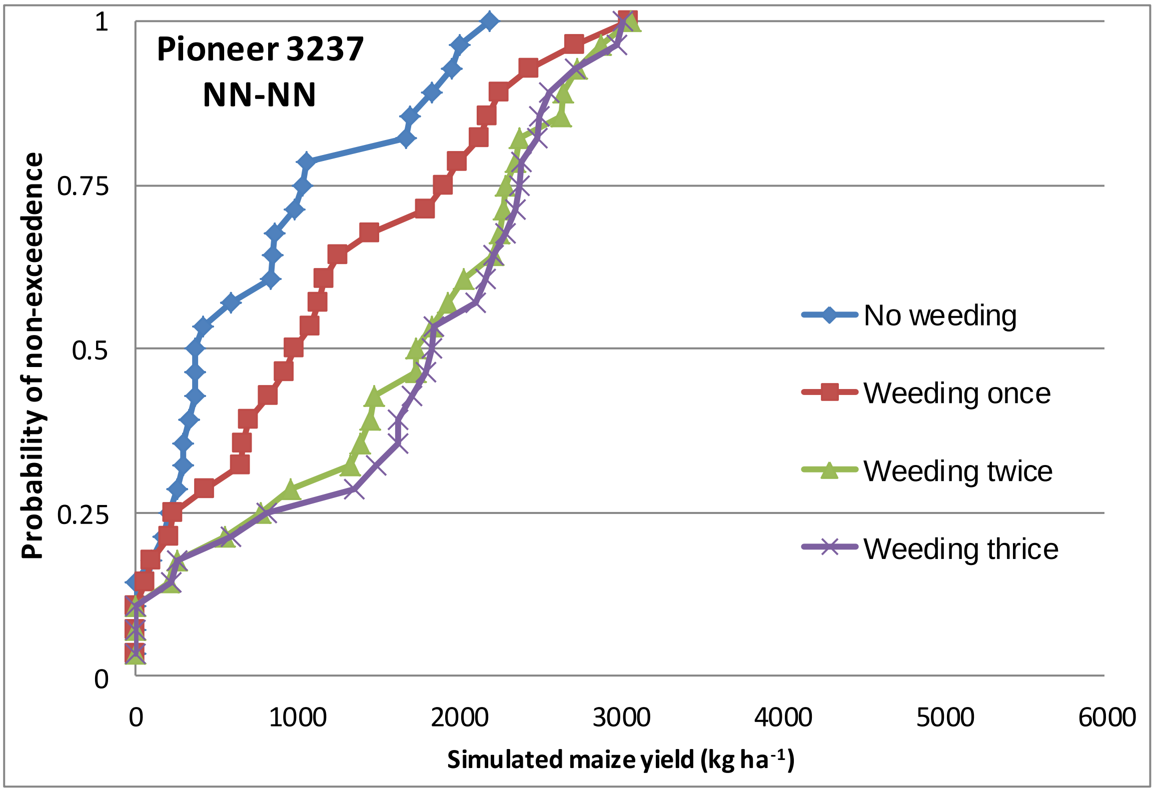


Figure 4.35: Cumulative distribution function of long-term simulated maize yields for Pioneer 3237 planted during 1-15 November under various weeding frequencies (using a plant population density of 9 000 plant ha^{-1} and fertiliser application rate of 35 kg ha^{-1} N).

The maize yield obtained without applying fertiliser was 520 kg ha^{-1} while a yield of 2 224 kg ha^{-1} corresponded to an application of 50 kg ha^{-1} N fertiliser at the 50% probability of non-exceedence level (Figure 4.34). Farmers could obtain an additional 430 kg ha^{-1} when applying 50 kg ha^{-1} N compared to 100 kg ha^{-1} N at the 75% probability level. This indicates that fertiliser application rates above 50 kg ha^{-1} N could lead to a decrease in maize yields during NN-NN rainfall conditions. For Pioneer 3237 (Figure 4.35), there was a 50% probability that the yield would not exceed 375 kg ha^{-1} without weeding and 1 834 kg ha^{-1} when weeding thrice. The yield difference between weeding 3 and 2 times was 95 kg ha^{-1}, while the yield difference between weeding twice and without weeding was 1 364 kg ha^{-1}.

The third and fourth ranked predictors for PAN 6479 were planting date and plant population density, respectively. For Pioneer 3237 it was the fertiliser application rate and plant population density (Table 4.7). Variance of the combination of planting dates and plant population densities with maize yields was 7.3% for PAN 6479, while for Pioneer 3237 the variance was 6.6%. For PAN 6479, these planting dates (1-15 November, 16-30 November and 1-15 November) and plant population densities (12 000 and 15 000 plants ha^{-1}) contributed highly to maize yields for PAN 6479 (not shown). For Pioneer 3237, the fertiliser application rates were 35 and 50 kg ha^{-1} N and plant population densities of 9 000, 12 000 and 18 000 plants ha^{-1} performed best (not shown).

4.3.7 Near-normal followed by below-normal (NN-BN) rainfall conditions

NN-BN rainfall conditions are characterised by average amounts of rainfall in the beginning of the growing season, followed by lower rainfall later in the season. Lower rainfall totals could cause moisture stress in the crucial stage of maize that can affect the development and grain filling. Table 3.4 indicate that 16 of 196 combined seasons were NN-BN rainfall conditions. The most significant yield predictors, as determined by stepwise regression, are shown in Table 4.8.

Table 4.8: Stepwise regression for predictors of maize yield during NN-BN rainfall conditions

Cultivar	Predictor Rank	Management Practice	Partial R^2
PAN 6479	1	Weeding Frequency	0.1335
	2	Planting Date	0.0920
	3	Fertiliser Application Rate	0.0215
	4	Plant Population Density	0.0005
Pioneer 3237	1	Planting Date	0.2370
	2	Weeding Frequency	0.1253
	3	Fertiliser Application Rate	0.0191

The results obtained from the stepwise regression showed that the highest ranked yield predictor for PAN 6479 was weeding frequency (partial R^2 of 0.1335), while for Pioneer 3237 it was planting date (partial R^2 of 0.237). The timing of planting date for PAN 6479 and optimum weeding frequency for Pioneer 3237 plays an important role in the growth and production of maize. Since any combination with the other management practices will indicate the significance of choosing different planting dates and weeding frequencies for Pioneer 3237 and PAN 6479, respectively, a random selection among the CDFs were made to illustrate this fact. The CDFs in Figure 4.36 and Figure 4.37 illustrate the variation of maize yields under different planting dates and weeding frequencies for PAN 6479 and Pioneer 3237, respectively.

For PAN 6479, maize without weeding and weeding twice yielded 81 and 1 244 kg ha^{-1}, respectively (Figure 4.36) at the 50% probability level. Farmers could thus obtain additional yield of 1 163 kg ha^{-1} N when opted to weed twice as opposed to no weeding. There was a low yield difference (18 kg ha^{-1}) between weeding 2 and 3 times at the 75% probability level.

Maize yield decreased as the planting date shifted later into the season for Pioneer 3237 (Figure 4.37). Farmers would obtain an additional 1 700 kg ha^{-1} when planting during 1-15 November rather than 16-30 December at the 75% probability level. Also the farmers ran the risk of crop failure when opting to plant during January under these seasonal rainfall conditions.

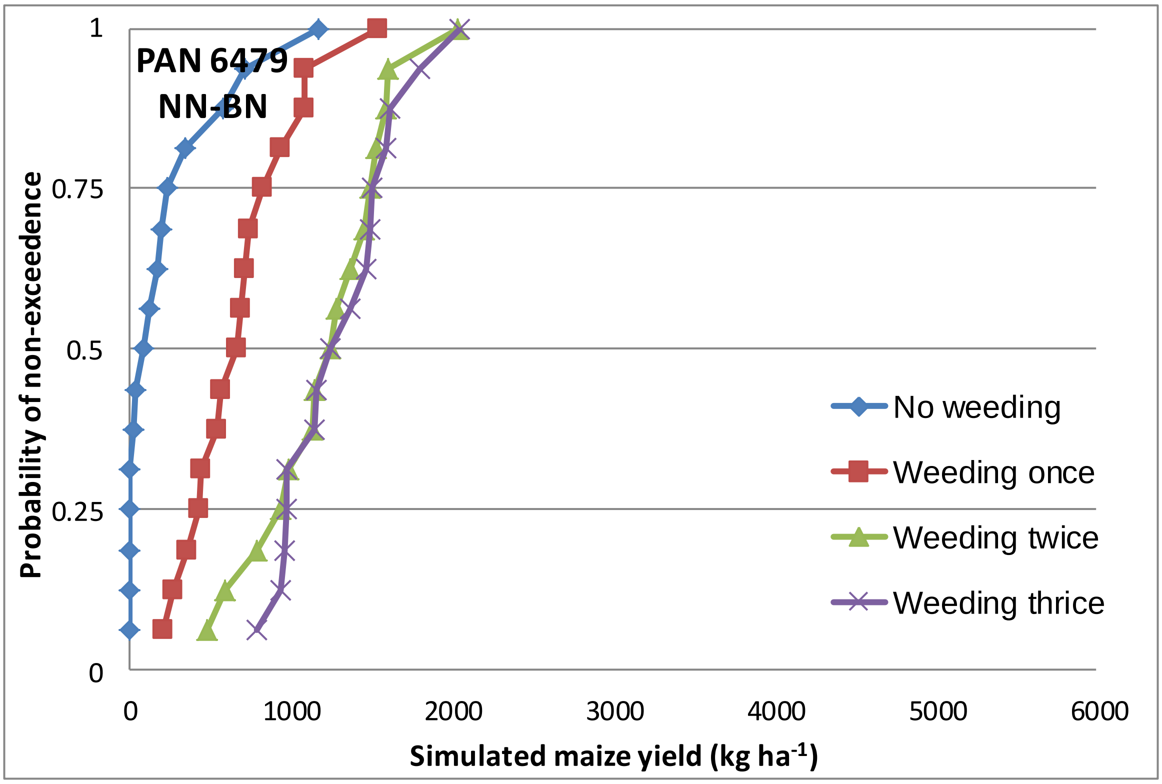


Figure 4.36: Cumulative distribution function of long-term simulated maize yields for PAN 6479 planted during 1-15 November under different weeding frequencies (using a plant population density of 12 000 plant ha^{-1} and fertiliser application rate of 50 kg ha^{-1} N).

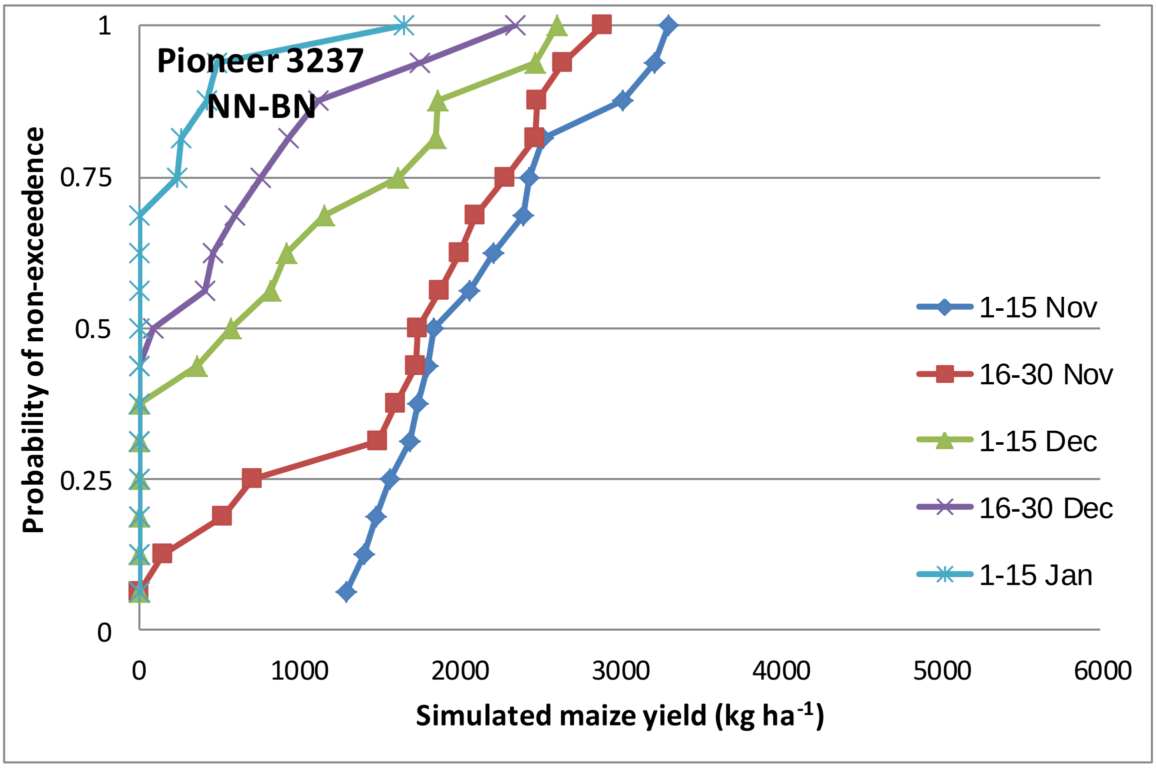


Figure 4.37: Cumulative distribution function of long-term simulated maize yields for Pioneer 3237 planted during different dates (using a plant population density of 12 000 plants ha^{-1}, fertiliser application rate of 50 kg ha^{-1} N and weeding thrice).

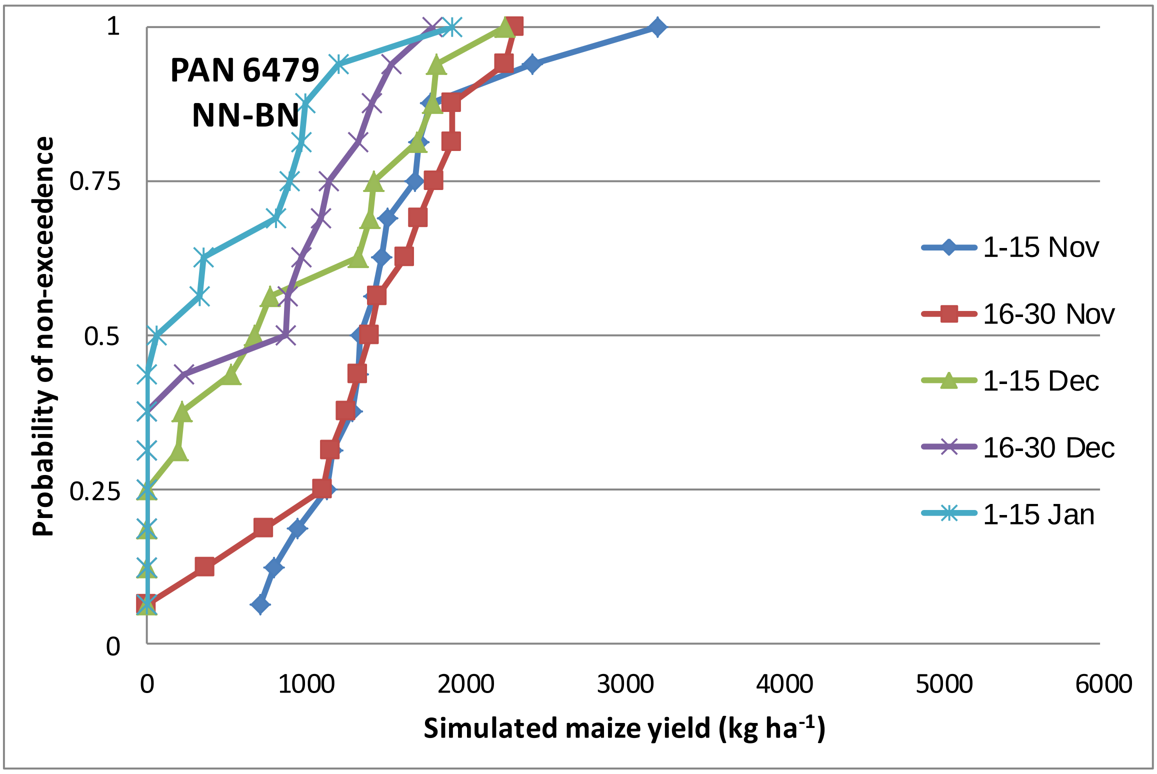


Figure 4.38: Cumulative distribution function of long-term simulated maize yields for PAN 6479 planted during different planting dates (using a plant population density of 15 000 plants ha^{-1}, fertiliser application rate of 50 kg ha^{-1} N and weeding twice).

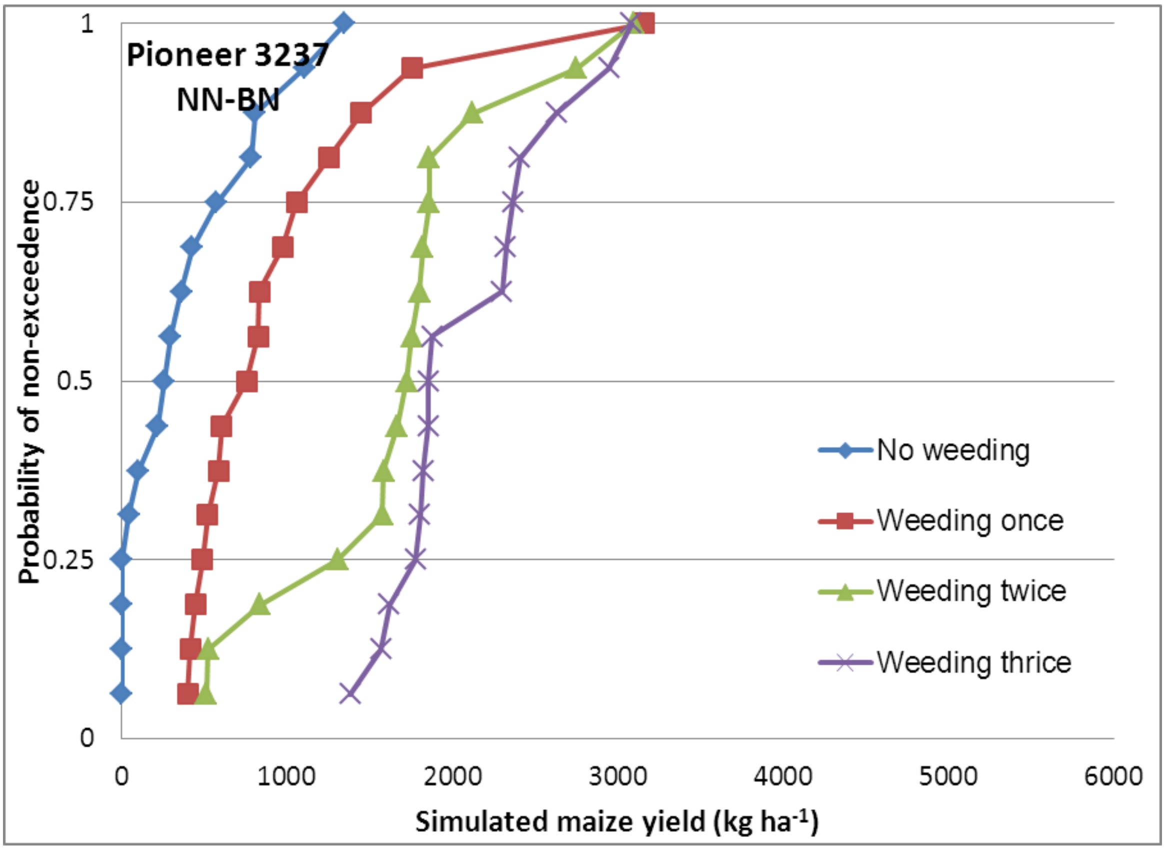


Figure 4.39: Cumulative distribution function of long-term simulated maize yields for Pioneer 3237 planted during 1-15 November under different weeding frequencies (using a plant population density of 9 000 plant ha^{-1} and fertiliser application rate of 50 kg ha^{-1} N).

The second ranked predictor for PAN 6479 was planting date (partial R^2 of 0.092), while weeding frequency (partial R^2 of 0.1253) was ranked second for Pioneer 3237 (Table 4.8). The CDFs in Figure 4.38 and Figure 4.39 illustrate the variation of maize yields under different planting dates and weeding frequencies for PAN 6479 and Pioneer 3237, respectively.

For PAN 6479 (Figure 4.38), the higher yields were obtained when utilising earlier planting dates during NN-BN rainfall conditions. An additional yield of 921 kg ha^{-1} could be obtained at the 75% probability level when planting during 16-30 November rather than 1-15 January. Planting before 16 November could decrease the yield by 284 kg ha^{-1} at the same probability level. This indicated that the best planting date was 16-30 November.

Maize yields increased with increasing weeding frequency for Pioneer 3237 (Figure 4.39). Farmers could expect a mere 258 kg ha^{-1} when producing maize without weeding, but the yield could increase to 1 857 kg ha^{-1} when weeding thrice at the 50% probability level. At the 75% probability level, the yield difference between weeding 2 and 3 times only 477 kg ha^{-1}.

The third and fourth ranked predictors were fertiliser application rate and plant population density for PAN 6479. For Pioneer 3237 only fertiliser application rate emerged as a significant predictor (Table 4.8). For PAN 6479, the fertiliser application rate found to contribute most to maize yield was 35 kg ha^{-1} N, while plant population densities of 9 000, 12 000 and 15 000 plants ha^{-1} contributed to higher maize yields (not shown). For Pioneer 3237, the fertiliser application rates found to contribute most were 35 and 50 kg ha^{-1} N, while a plant population density of 9 000 plants ha^{-1} emerged as the top treatment (not shown).

4.3.8 Below-normal followed by above-normal (BN-AN) rainfall conditions

BN-AN rainfall conditions are characterised by low and erratic rainfall patterns at the beginning of the season, followed by high rainfall conditions later in the season. These rainfall scenarios could affect early planted maize due to moisture stress during the early growth stages (Molua & Lambi, 2006). For 196 years of combined rainfall data there were 24 BN-AN seasons. A stepwise regression was employed to screen the various management practices in order to determine the most significant yield predictors (Table 4.9).

Table 4.9: Stepwise regression for predictors of maize yield during BN-AN rainfall conditions

Cultivar	Predictor Rank	Management Practice	Partial R^2
PAN 6479	1	Fertiliser Application Rate	0.0965
	2	Planting Date	0.0671
	3	Weeding Frequency	0.0658
	4	Plant Population Density	0.0324
Pioneer 3237	1	Planting Date	0.1920
	2	Fertiliser Application Rate	0.0749
	3	Weeding Frequency	0.0423
	4	Plant Population Density	0.0069

The results obtained from the stepwise regression showed that for PAN 6479 the highest ranked yield predictor was fertiliser application rate (partial R^2 of 0.0965), while for Pioneer 3237 planting date was the most important (partial R^2 of 0.1920). The CDFs in Figure 4.40 and Figure 4.41 illustrate the variation of maize yields under different fertiliser application rates for PAN 6479 and different planting dates for Pioneer 3237, respectively.

For PAN 6479, the optimum fertiliser application rate during BN-AN rainfall conditions was 35 kg ha^{-1} N (Figure 4.40). The 50% probability of non-exceedence illustrated that without fertilisers the yield was only 396 kg ha^{-1} and at 35 kg ha^{-1}N the yield increased to 1 180 kg ha^{-1}. There is a 75% probability that the maize yield will not exceed 1 361, 1 356, 1353 and 1 351 kg ha^{-1} when applying 35, 50, 75 and 100 kg ha^{-1} N of fertiliser. This showed that fertiliser application rates above 35 kg ha^{-1} N would lead to non-incremental maize yields.

During these seasonal rainfall conditions maize yield decreased as the planting date shifted later in the season for Pioneer 3237 (Figure 4.41). At a 50% probability of non-exceedence maize planted during 1-15 November, 1-15 December and 1-15 January corresponded to yields of 1 314, 698 and 86 kg ha^{-1}, respectively. This showed that the yield loss for maize planted during

January as opposed to planting during early November could be more than 1 000 kg ha^{-1}.

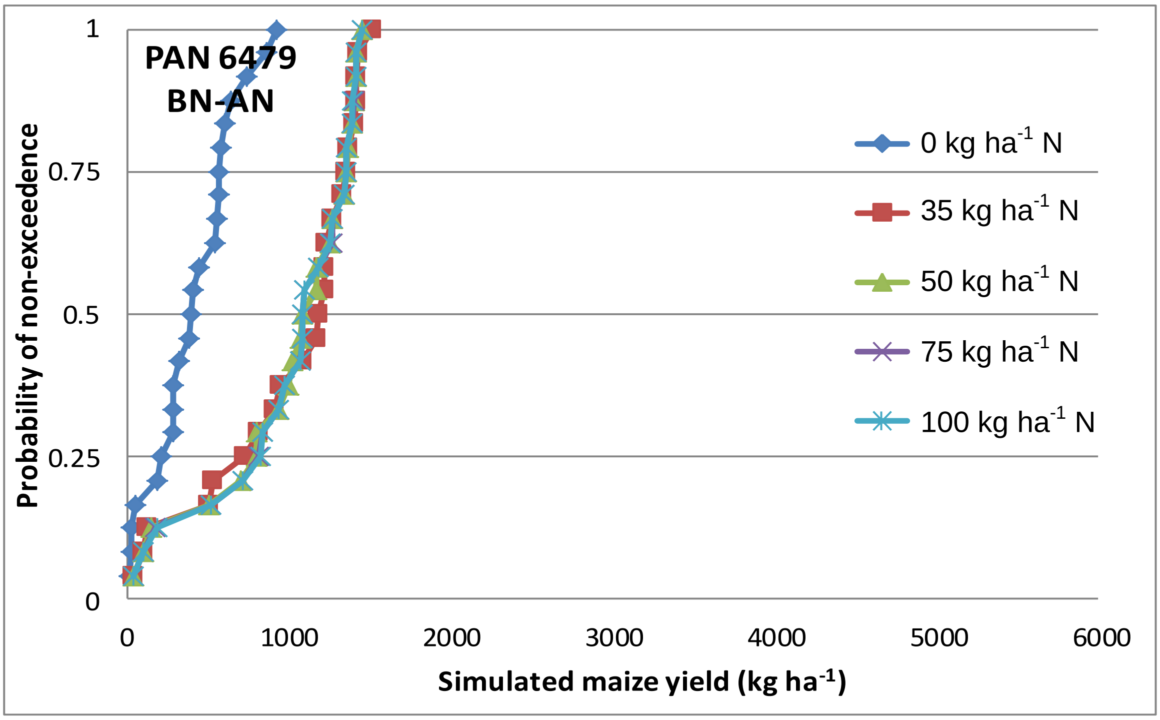


Figure 4.40: Cumulative distribution function of long-term simulated maize yields for PAN 6479 planted during 16-30 November under various fertiliser application rates (using a plant population density of 9 000 plants ha^{-1} and weeding once).

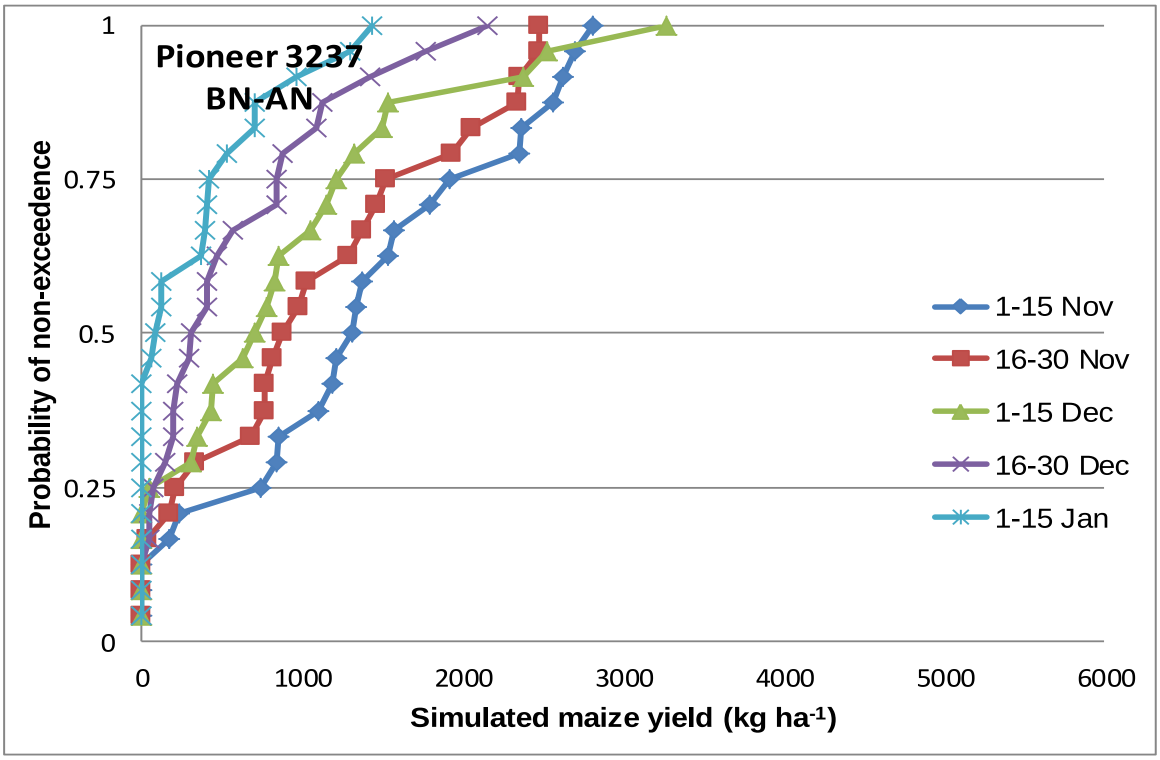


Figure 4.41: Cumulative distribution function of long-term simulated maize yields for Pioneer 3237 planted during different dates (using a plant population density of 12 000 plants ha^{-1}, fertiliser application rate of 35 kg ha^{-1} N and weeding once).

The second ranked predictor found to influence the contribution to maize yield was planting date and fertiliser application rate for PAN 6479 and Pioneer 3237, respectively. A partial R^2 of 0.0671 and 0.0749 were obtained for PAN 6479 and Pioneer 3237, respectively (Table 4.9). The CDFs in Figure 4.42 and Figure 4.43 illustrate the variation of maize yields under different planting dates and fertiliser application rates for these two cultivars.

For PAN 6479, maize yields also decreased as the planting date shifted later into the season. A farmer would obtain only 417 kg ha^{-1} when opting to plant during 1-15 January rather than 1-15 November at the 50% probability level (Figure 4.41). This implies that the best planting date is between 1-30 November, since the 50 and 75% probability level indicates that planting after 30 November decreased maize yields.

For Pioneer 3237 (Figure 4.43), higher maize yields required optimum fertiliser application rates. At the 50% probability level, the maize yield with no fertilisers was 533 kg ha^{-1}, while applying 75 kg ha^{-1} N yielded 1 617 kg ha^{-1}. The yield difference between 75 and 100 kg ha^{-1} N was only 15 kg ha^{-1}, while the yield difference between 50 and 75 kg ha^{-1} N was 1 467 kg ha^{-1} at the 75% probability level.

The third and fourth ranked predictors for both cultivars were weeding frequency and plant population density, with a combined partial R^2 of 0.0972 and 0.0492 (Table 4.9) for PAN 6479 and Pioneer 3237, respectively. For PAN 6479, weeding frequencies found to contribute highest to maize yield were 2 and 3 times, while the plant population densities producing high yield were 12 000, 15 000 and 21 000 plants ha^{-1} (not shown). For Pioneer 3237, weeding once or twice were found to contribute most to maize yields, with the higher yielding plant population densities of 15 000, 18 000 and 21 000 plants ha^{-1} (not shown).

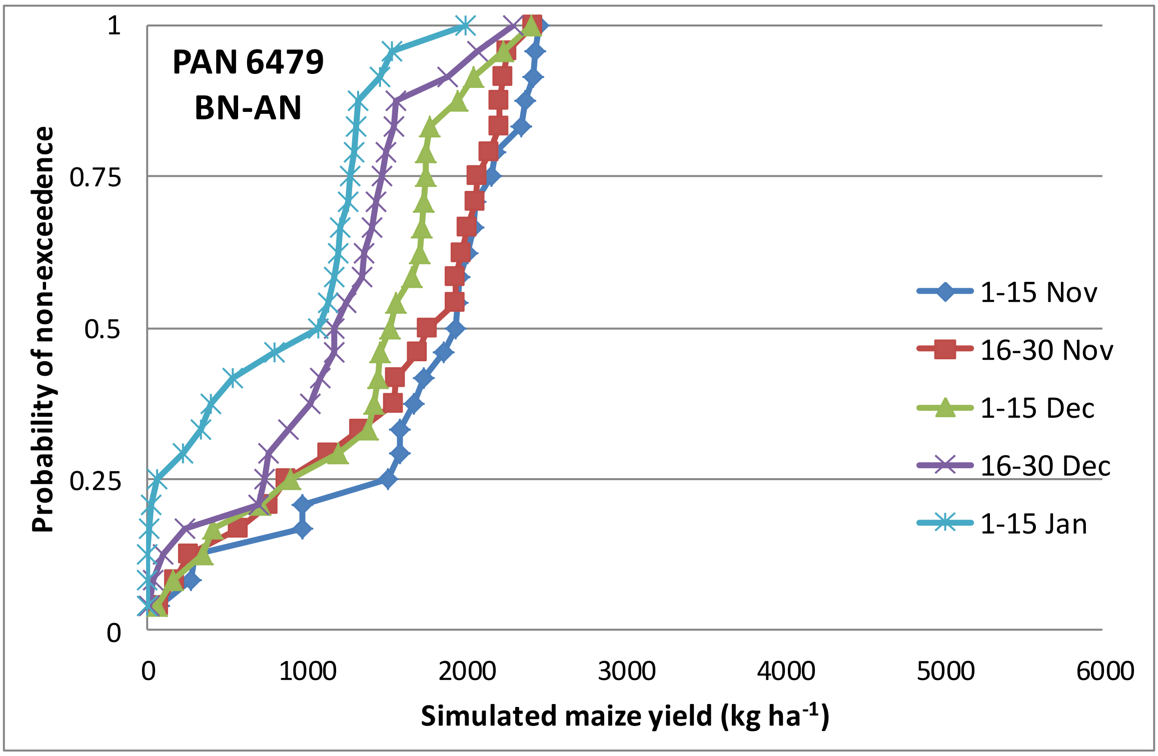


Figure 4.42: Cumulative distribution function of long-term simulated maize yields for PAN 6479 planted during different dates (using a plant population density of 15 000 plants ha^{-1}, fertiliser application rate of 35 kg ha^{-1} N and weeding twice).

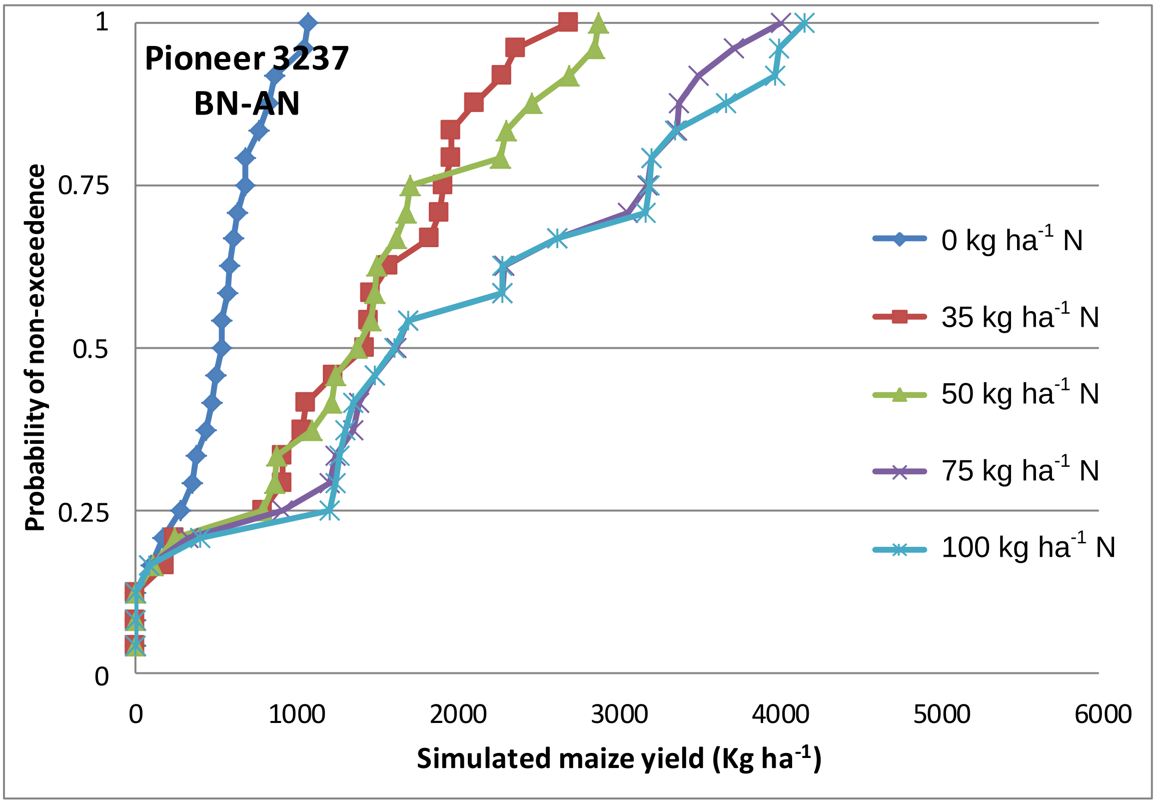


Figure 4.43: Cumulative distribution function of long-term simulated maize yields for Pioneer 3237 planted during 1-15 November under different fertiliser application rates (using a plant population density of 15 000 plants ha^{-1} and weeding once).

4.3.9 Below-normal followed by near-normal (BN-NN) rainfall conditions

BN-NN rainfall conditions are also characterised by low and erratic rainfall patterns at the beginning of the growing season, followed by average amounts of rainfall later in the season. Table 3.4 indicate that 23 of 196 combined seasons were BN-NN scenarios. The most significant yield predictors, as determined by the stepwise regression, are shown in Table 4.10.

Table 4.10: Stepwise regression for predictors of maize yield during BN-NN rainfall conditions

Cultivar	Predictors rank	Management Practice	Partial R^2
PAN 6479	1	Planting Date	0.1054
	2	Weeding Frequency	0.0998
	3	Fertiliser Application Rate	0.0433
	4	Plant Population Density	0.0090
Pioneer 3237	1	Planting Date	0.1915
	2	Weeding Frequency	0.0550
	3	Fertiliser Application Rate	0.0352
	4	Plant Population Density	0.0019

Table 4.10 indicated that both cultivars had the same predictor ranking during BN-NN seasons. The yield predictor that was found to dominate the contribution to maize yield was the planting date (Table 4.10) with a partial R^2 of 0.1054 for PAN 6479 and 0.1915 for Pioneer 3237, respectively. Since any combination with the other management practices will indicate the significance of choosing different planting dates, a random selection among the CDFs were made to illustrate this fact. The CDFs in Figure 4.44 and Figure 4.45 illustrate the variation of maize yields under different planting dates for PAN 6479 and Pioneer 3237, respectively.

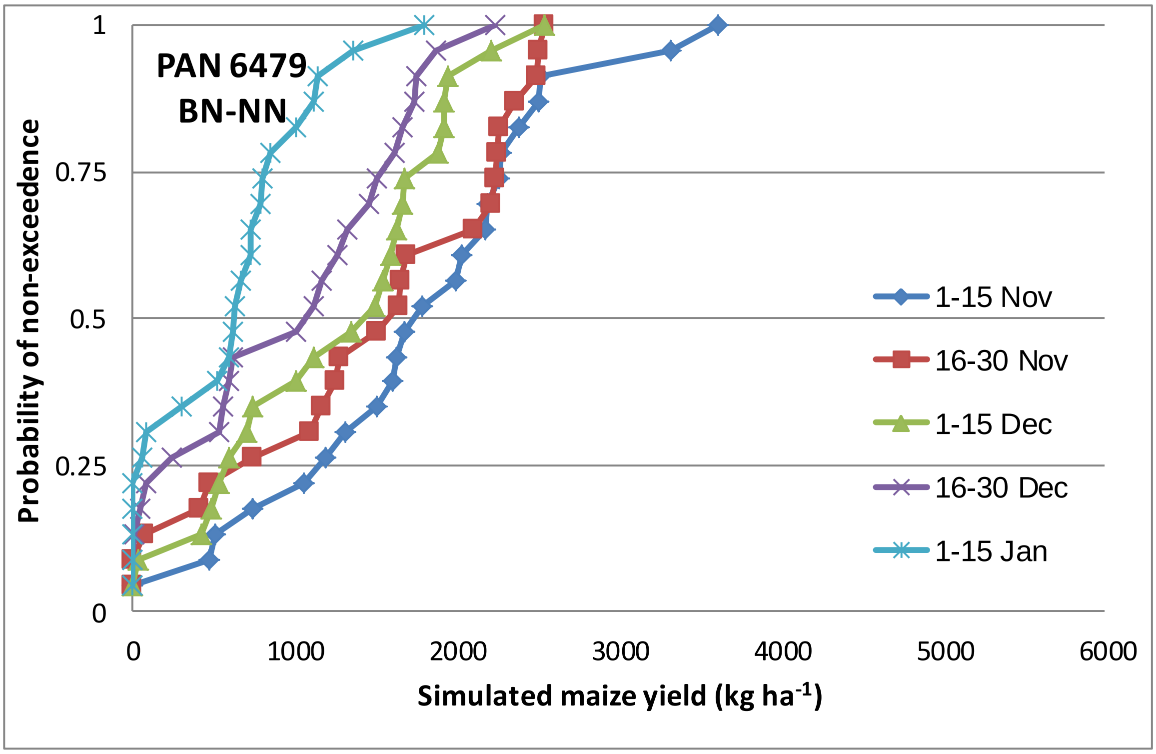


Figure 4.44: Cumulative distribution function of long-term simulated maize yields of PAN 6479 planted during different dates (using a plant population density of 15 000 plants ha^{-1}, fertiliser application rate of 50 kg ha^{-1} N and weeding twice).

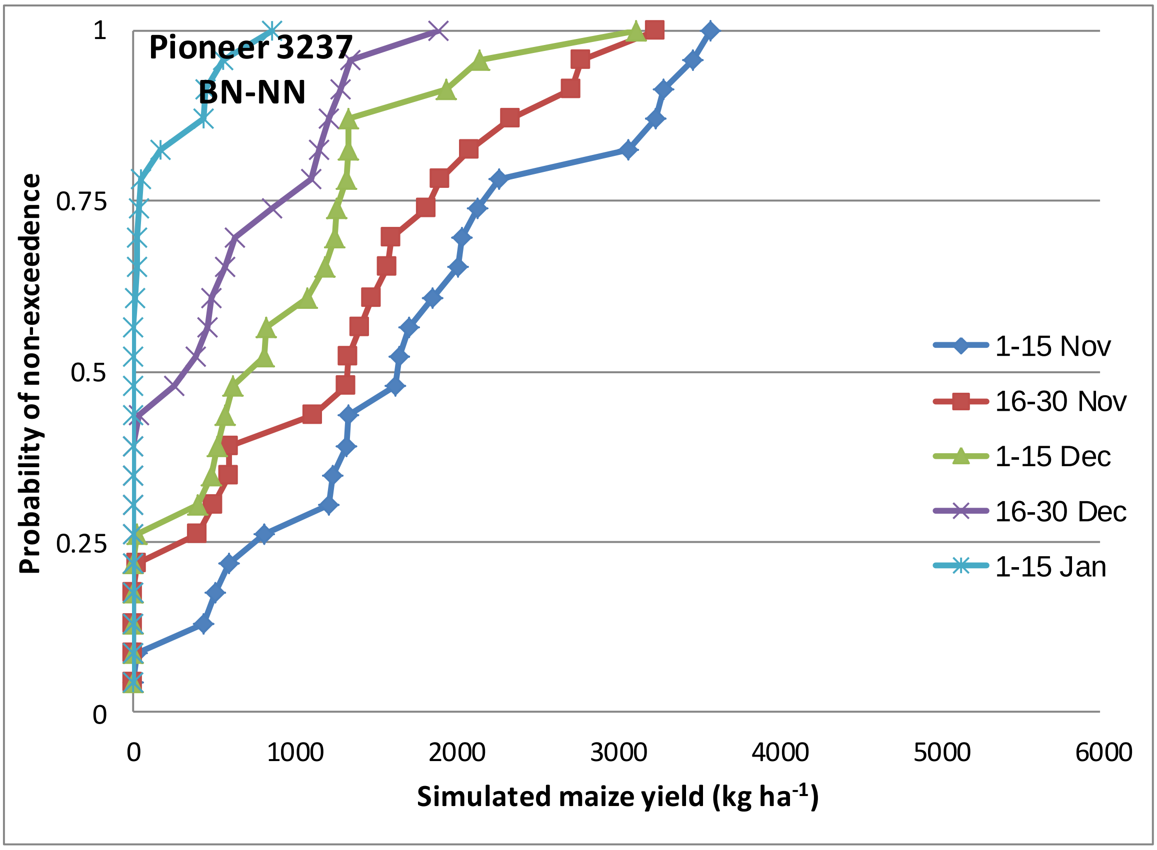


Figure 4.45: Cumulative distribution function of long-term simulated maize yields of Pioneer 3237 planted during different dates (using a plant population density of 15 000 plants ha^{-1}, fertiliser application rate of 50 kg ha^{-1} N and weeding thrice).

Both Figures 4.44 and 4.45 show that under BN-NN rainfall conditions planting earlier produced high maize yields. For PAN 6479, maize planted during 1-15 November, 1-15 December and 1-15 January yielded to 1 782, 1 493 and 631 kg ha^{-1}, respectively at the 50% probability level. At the same probability level a farmer would run the risk of crop failure if opting to plant Pioneer 3237 during 1-15 January.

The second ranked maize yield predictor was weeding frequency. The contribution of weeding frequency to maize yield variation in terms of partial R^2 for PAN 6479 and Pioneer 3237 were 0.0998 and 0.055, respectively (Table 4.10). According to Raiz *et al.* (2007) removing weeds from maize fields is important, since the persistence, density and the type of weed could determine the magnitude of maize yield loss. The CDFs in Figure 4.46 and Figure 4.47 illustrate the variation of maize yield under different weeding frequencies for PAN 6479 and Pioneer 3237, respectively.

For PAN 6479, the 50% probability of non-exceedence indicates that planting maize without weeding and weeding twice yielded 310 and 1 769 kg ha^{-1} (Figure 4.46). This showed that a farmer could lose as much as 1 459 kg ha^{-1}. At the 75% probability of non-exceedence maize yields under 1, 2 or 3 times of weeding resulted in yields of 1 590, 2 365 and 2 324 kg ha^{-1}. The yield difference between weeding 2 and 3 times was less than 41 kg ha^{-1}. Therefore, weeding twice would be significant. For Pioneer 3237, there was a 75% probability that the maize yield will not exceed 1 189, 1 597, 2 365 or 2 612 kg ha^{-1} when weeding 0, 1, 2 or 3 times respectively (Figure 4.47). This showed that the maize yield increased with weeding frequency and produced the highest yield when weeding thrice.

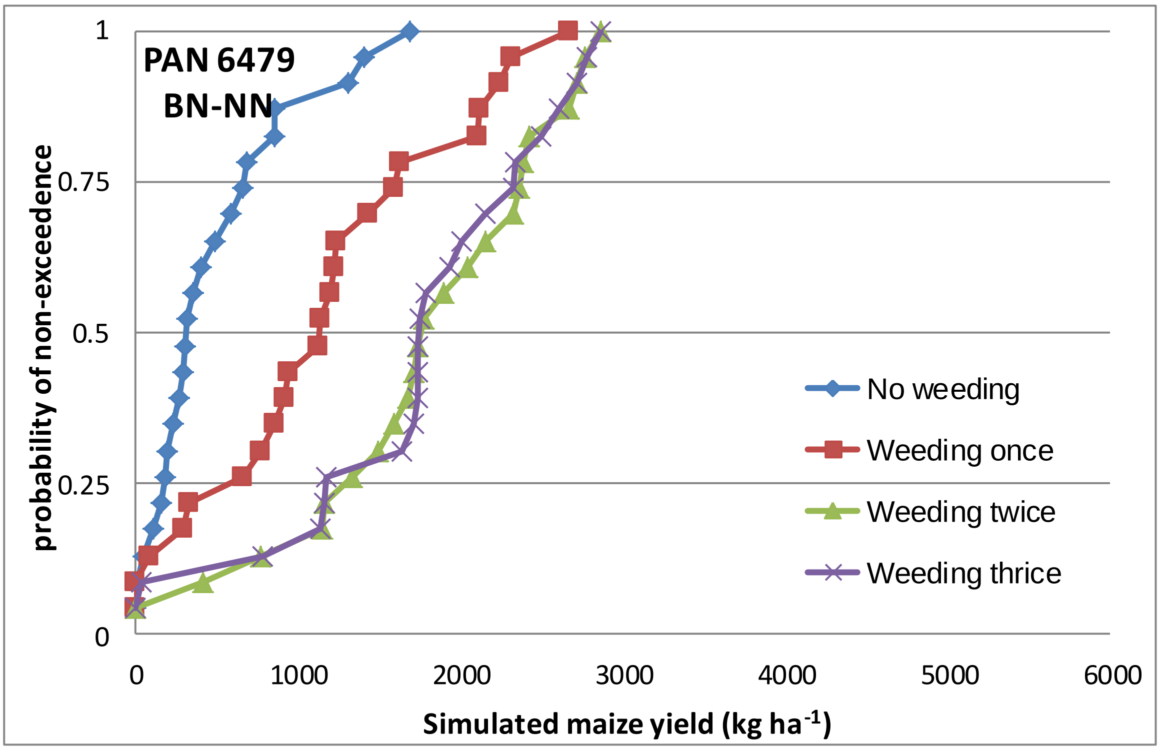


Figure 4.46: Cumulative distribution function of long-term simulated maize yields for PAN 6479 planted during 1-15 November under different weeding frequencies (using a plant population density of 18 000 plant ha^{-1} and fertiliser application rate of 50 kg ha^{-1} N).

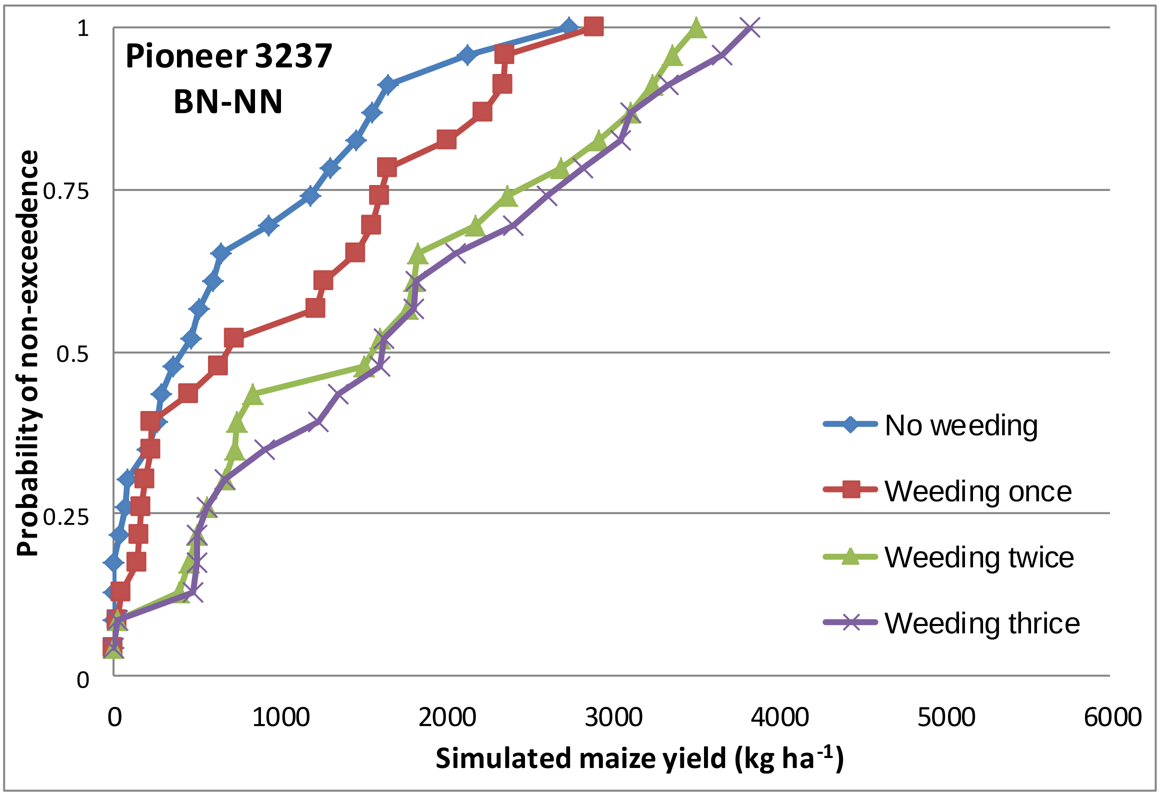


Figure 4.47: Cumulative distribution function of long-term simulated maize yields for Pioneer 3237 planted during 1-15 November under different weeding frequencies (using a plant population density of 12 000 plant ha^{-1} and fertiliser application rate of 50 kg ha^{-1} N).

For both cultivars, the third and fourth ranked predictors were fertiliser application rate and plant population density, respectively, where the combined partial R^2 made a total of 0.0523 and 0.0371 for PAN 6479 and Pioneer 3237, respectively (Table 4.10). For PAN 6479, the fertiliser application rates found to contribute most to maize yields were 35 and 50 kg ha^{-1} N, while the highest yielding plant population densities were 9 000, 12 000 and 15 000 plants ha^{-1} (not shown). For Pioneer 3237, fertiliser application rates found to contribute most to maize yields were also 35 and 50 kg ha^{-1} N, while the plant population densities of 9 000, 12 000, 15 000 and 18 000 plants ha^{-1} performed best (not shown).

4.3.10 Below-normal followed by below-normal (BN-BN) rainfall conditions

BN-BN rainfall scenarios are characterised by low and erratic rainfall patterns during the entire cropping season. These rainfall scenarios cause moisture stress which affects maize growth, development and thus lowers the yield. In the most drastic cases it may result in crop failures. In the 196 years of combined rainfall data there were 17 BN-BN seasons. The most significant yield predictors, as determined by stepwise regression, are shown in Table 4.11.

Table 4.11: Stepwise regression for predictors of maize yield during BN-BN rainfall conditions

Cultivar	Predictor Rank	Management Practice	Partial R^2
PAN 6479	1	Planting Date	0.1240
	2	Weeding Frequency	0.0601
	3	Fertiliser Application Rate	0.0118
	4	Plant Population Density	0.0002
Pioneer 3237	1	Planting Date	0.1840
	2	Weeding Frequency	0.0901
	3	Fertiliser Application Rate	0.0108
	4	Plant Population Density	0.0003

Both cultivars revealed the same rank in yield predictors. The highest ranked predictor under BN-BN rainfall conditions for both cultivars was planting date (partial R^2 of 0.124 and 0.184 for PAN 6479 and Pioneer 3237, respectively). Since any combination with the other management practices will indicate the significance of choosing different planting dates, a random selection among the CDFs were made to illustrate this fact. The CDFs in Figure 4.48 and Figure 4.49

illustrate the variation of maize yields under different planting dates for PAN 6479 and Pioneer 3237, respectively.

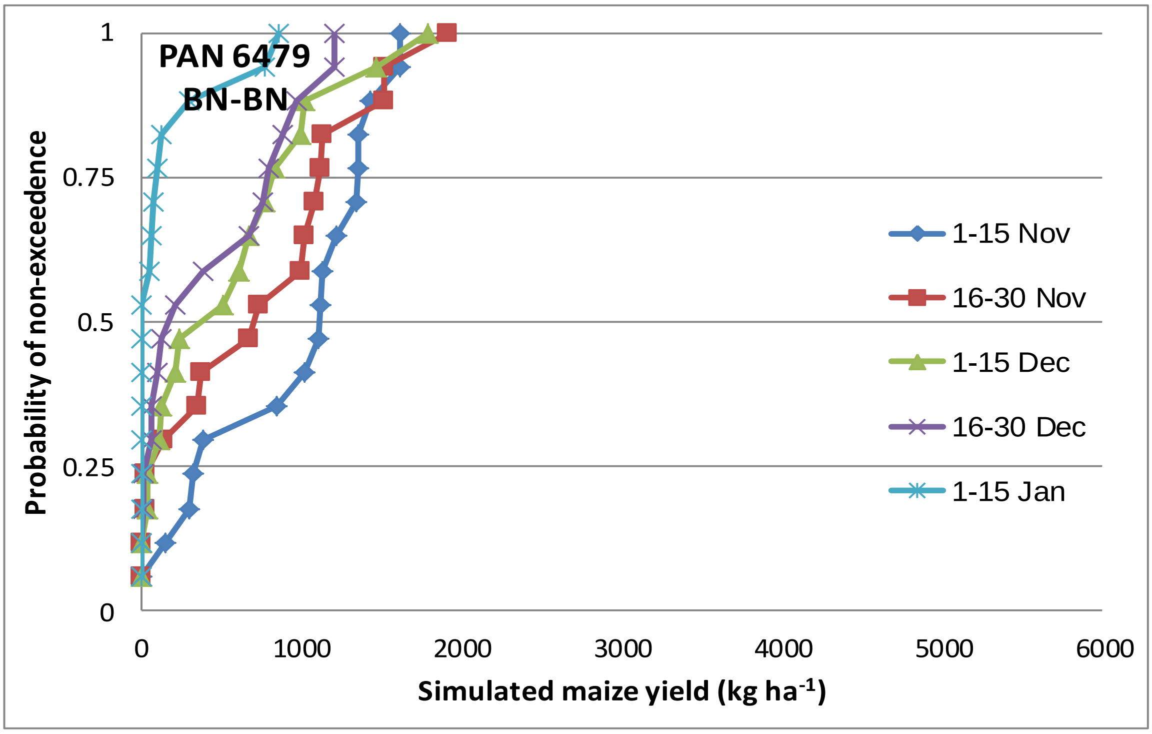


Figure 4.48: Cumulative distribution function of long-term simulated maize yields of PAN 6479 planted during different dates (using a plant population density of 12 000 plants ha^{-1}, fertiliser application rate of 35 kg ha^{-1} N and weeding once).

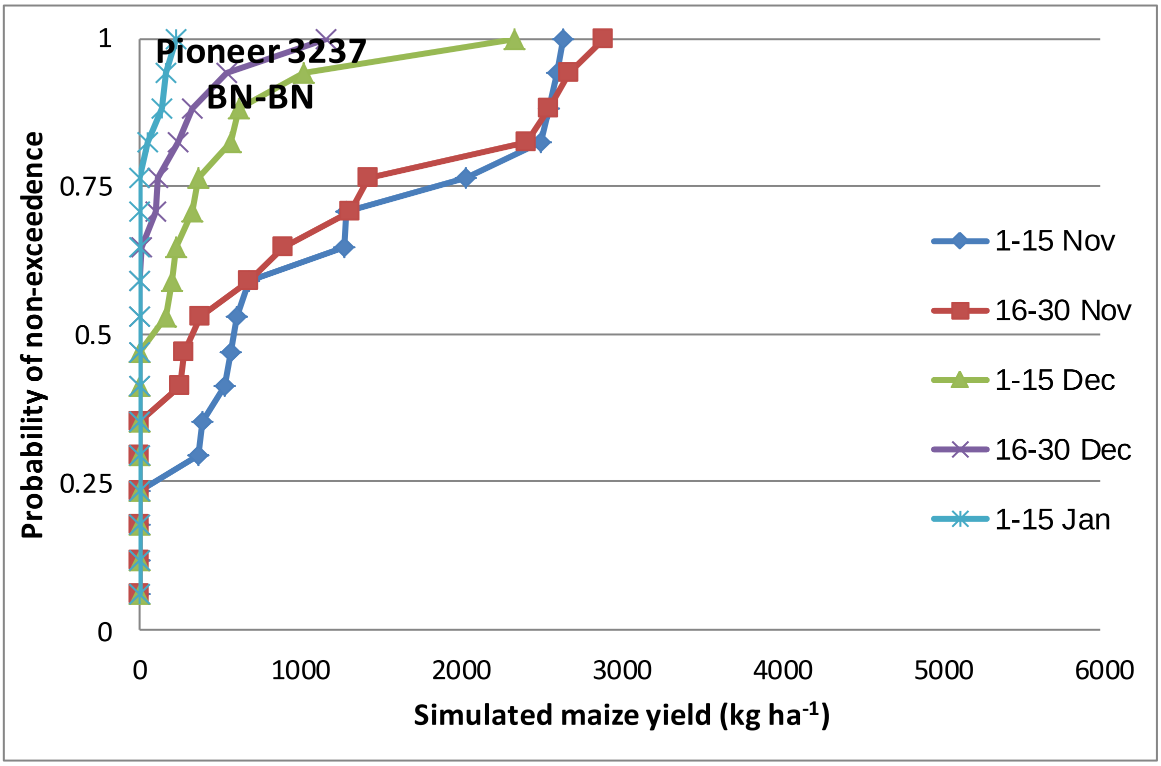


Figure 4.49: Cumulative distribution function of long-term simulated maize yields of Pioneer 3237 planted during different dates (using a plant population density of 12 000 plants ha^{-1}, fertiliser application rate of 50 kg ha^{-1} N and weeding once).

For both cultivars planting earlier could produce higher maize yield (Figures 4.48 and 4.49). For PAN 6479, there was a 50% probability that the maize yield would not exceed 1 126, 740, 515, 211 and 8 kg ha^{-1} when planted during 1-15 November, 16-30 November, 1-15 December, 16-30 December and 1-15 January, respectively. Not surprisingly, the maize yields remained low compared to other seasonal rainfall conditions. Again Pioneer 3237 performed better than PAN 6479 during these conditions, since at the 75% probability level the maize planted during 1-15 November yielded 1 353 kg ha^{-1} and 2 681 kg ha^{-1} for PAN 6479 and Pioneer 3237, respectively.

The second ranked yield predictor for both cultivars was weeding frequency. The contribution of weeding frequency on variation of maize yields in terms of partial R^2 for PAN 6479 and Pioneer 3237 were 0.0601 and 0.0901 (Table 4.11), respectively. The CDFs in Figure 4.50 and Figure 4.51 are for PAN 6479 and Pioneer 3237, respectively.

For PAN 6479 (Figure 4.50), the maize yields corresponding to 0, 1, 2 or 3 times were 229, 1 086, 1 372 or 1 227 kg ha^{-1} at the 50% probability level. The yield difference between weeding thrice and twice was less by 145 kg ha^{-1}. The optimum frequency was therefore 2 times. Maize yields for Pioneer 3237 generally increased with increment of weeding frequency during BN-BN rainfall conditions (Figure 4.51). At the 50% probability of non-exceedence maize yields of 424, 1 311, 2 035 and 2 085 kg ha^{-1} corresponded to 0, 1, 2 and 3 times of weeding. The yield difference between weeding 2 and 3 times was only 50 kg ha^{-1}.

For both cultivars, the third and fourth ranked predictors were fertiliser application rate and plant population density, respectively. The contribution of fertiliser application rates and plant population densities on maize yield in terms of combined partial R^2 were 0.012 and 0.011 for PAN 6479 and Pioneer 3237, respectively. For PAN 6479, the fertiliser application rate found to contribute most to maize yields was 35 kg ha^{-1} N, while the best plant population densities were 9 000 and 12 000 plants ha^{-1} (not shown). For Pioneer 3237, fertiliser application rates found to contribute most to maize yields were 35 and 50 kg ha^{-1} N, while again plant population densities of 9 000 and 12 000 plants ha^{-1} performed best (not shown).

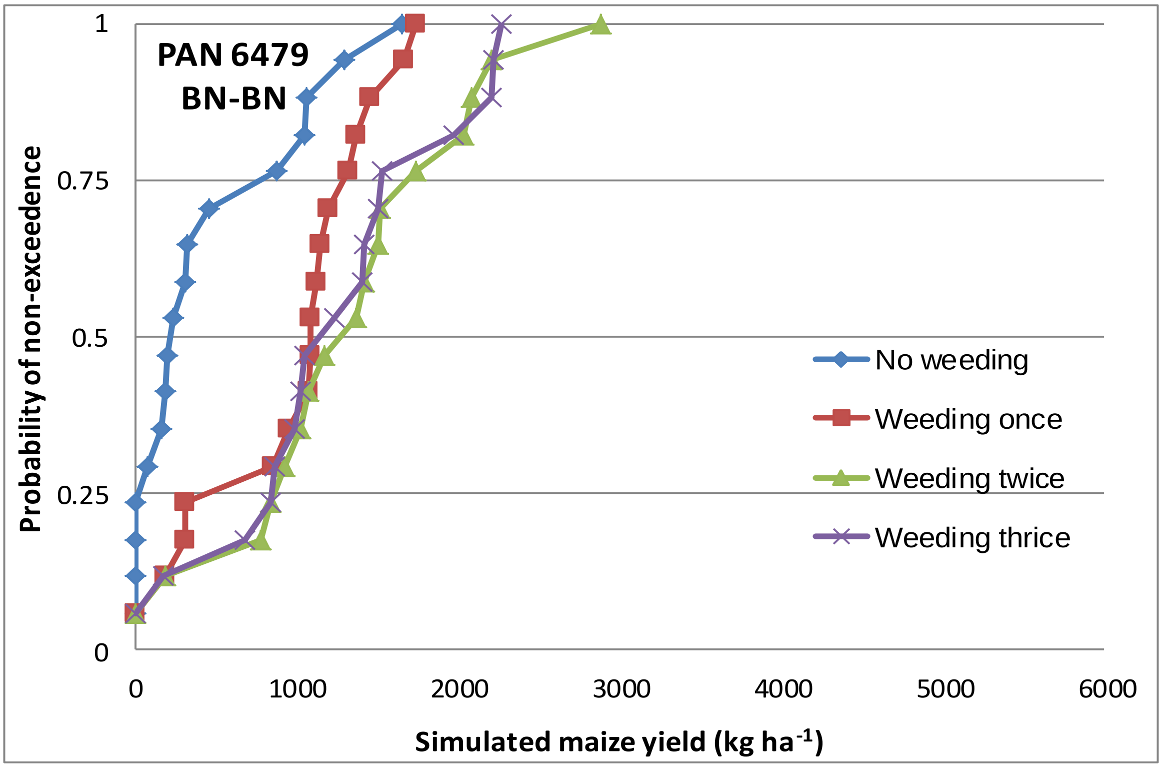


Figure 4.50: Cumulative distribution function of long-term simulated maize yields for PAN 6479 planted during 1-15 November under different weeding frequencies (using a plant population density of 15 000 plant ha^{-1} and fertiliser application rate of 50kg ha^{-1} N).

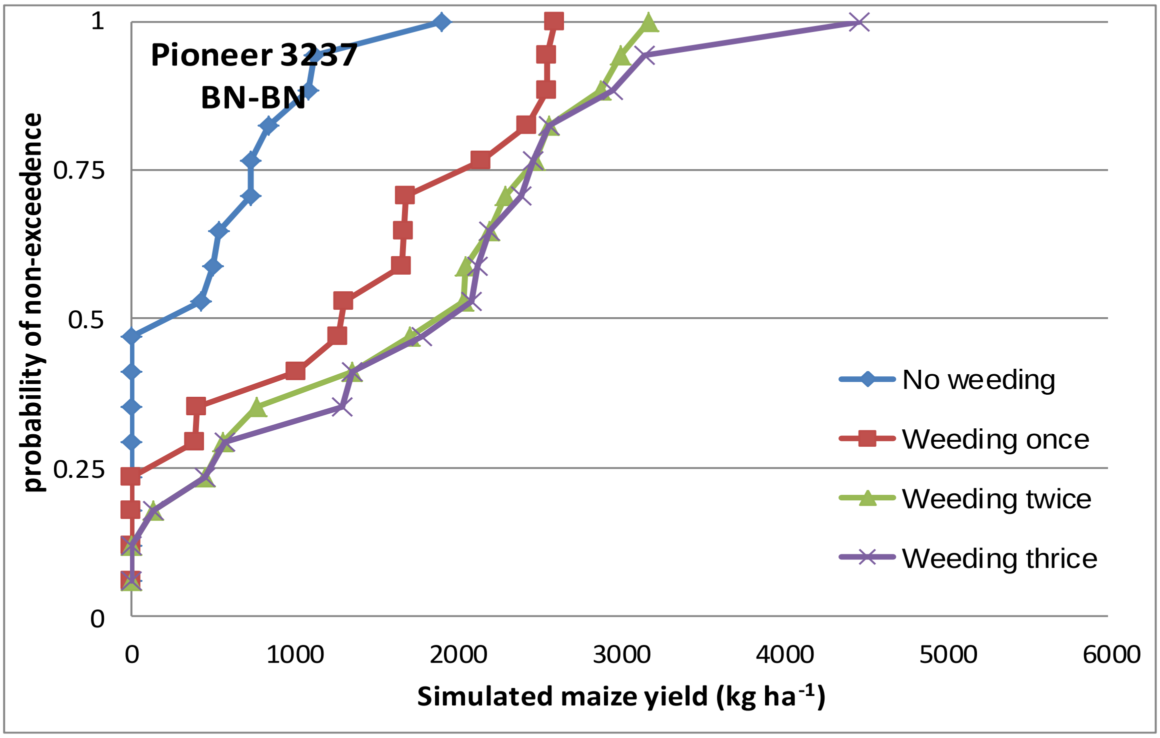


Figure 4.51: Cumulative distribution function of long-term simulated maize yields for Pioneer 3237 planted during 1-15 November under different weeding frequencies (using a population density of 15 000 plant ha^{-1} and fertiliser application rate of 50kg ha^{-1} N).

4.4 Comparative economic benefit of different management decisions under various seasonal rainfall conditions

4.4.1 Background

Management practices that contributed significantly to maize yield were identified in section 4.3. The various sets of management practices exhibiting the highest yield potential were subjected to an economical analysis. This was done in order to determine whether the income generated by the potential yields actually warranted the additional field costs involved. Field costs for each set of management practices were calculated and compared to alternative sets in order to determine the additional cost involved. Potential incomes generated by the expected maize yields were also determined at the 25, 50 and 75% probability levels (as depicted by the CDFs in section 4.3). The economic benefit of each set was determined by calculating the gross margins as the difference between the yield income and associated field cost. In this case the 25% probability of non-exceedence was used to assess the financial risk, while 75% was used to assess potential financial benefits. Gross margins were compared in order to identify a set of optimum management practices under each seasonal rainfall scenario.

For Pioneer 3237 (Figure 4.15) it was found that the maize yield under 0 and 35 kg ha^{-1} N of fertiliser application rate corresponded to 703 and 2 307 kg ha^{-1} at the 50% probability level. By simply adding 35 kg ha^{-1} N, the farmer can increase the yield by 1 604 kg ha^{-1}. At the 75% probability level fertiliser application rates of 35, 50, 75 and 100 kg ha^{-1} N corresponded to 2 597, 3 316, 4 342 and 4 414 kg ha^{-1}, respectively. The yield difference between 75 and 35 kg ha^{-1} N was 1 745 kg ha^{-1}, while the yield difference between 100 and 75 kg ha^{-1} N was just 62 kg ha^{-1}.

Readers are again advised that the economic analysis presented in this section cannot be used in practice to advice farmers as the model’s validation was not satisfactory. However, it was deemed important to assess the influence of various management practices on the gross margins for the two medium growth period cultivars under different seasonal rainfall conditions.

4.4.2 Economic analysis of above-normal followed by above-normal (AN-AN) rainfall conditions

The combinations of yield predictors that were subjected to the economic analysis are provided in Table A1 for PAN 6479 and Table A2 for Pioneer 3237 of Appendix A. The economic benefits associated with each set of management practices are shown in Appendix B Table B1 for PAN 6479 and Table B2 for Pioneer 3237.

The statistical analysis of the simulated maize yields presented in section 4.3.2 showed that the choice of planting date was the most significant management practice for maize production, while plant population density was the least significant for both PAN 6479 and Pioneer 3237. From the data presented in Table B1 (Appendix B) it is evident that the optimum fertiliser application rate was 50 kg ha^{-1} N, while the optimum weeding frequency was 2 times for PAN 6479. For Pioneer 3237 (Table B2, Appendix B), the optimum fertiliser application rate was 75 kg ha^{-1} N, with an optimum weeding frequency of 2 times.

Economic analysis of the different sets of management practices showed that under optimum fertiliser application rate and weeding frequency a close relationship existed between the planting dates and plant population densities for both cultivars (see Table B1 and Table B2 in Appendix B). For PAN 6479, planting dates of 1-15 November, 16-30 November and 1-15 December produced higher yields than 16-30 December and 1-15 January. Plant population densities that produced high yields were 18 000 and 21 000 plants ha^{-1} (see section 4.3.2). For Pioneer 3237, the planting dates that yielded the most were 1-15 November and 16-30 November, with plant population densities of 15 000, 18 000 and 21 000 plants ha^{-1} (see section 4.3.2). The CDFs in Figures 4.52 and 4.53 illustrate the economic benefit associated with three different planting dates and two plant population densities during AN-AN rainfall seasons for PAN 6479 and Pioneer 3237, respectively.

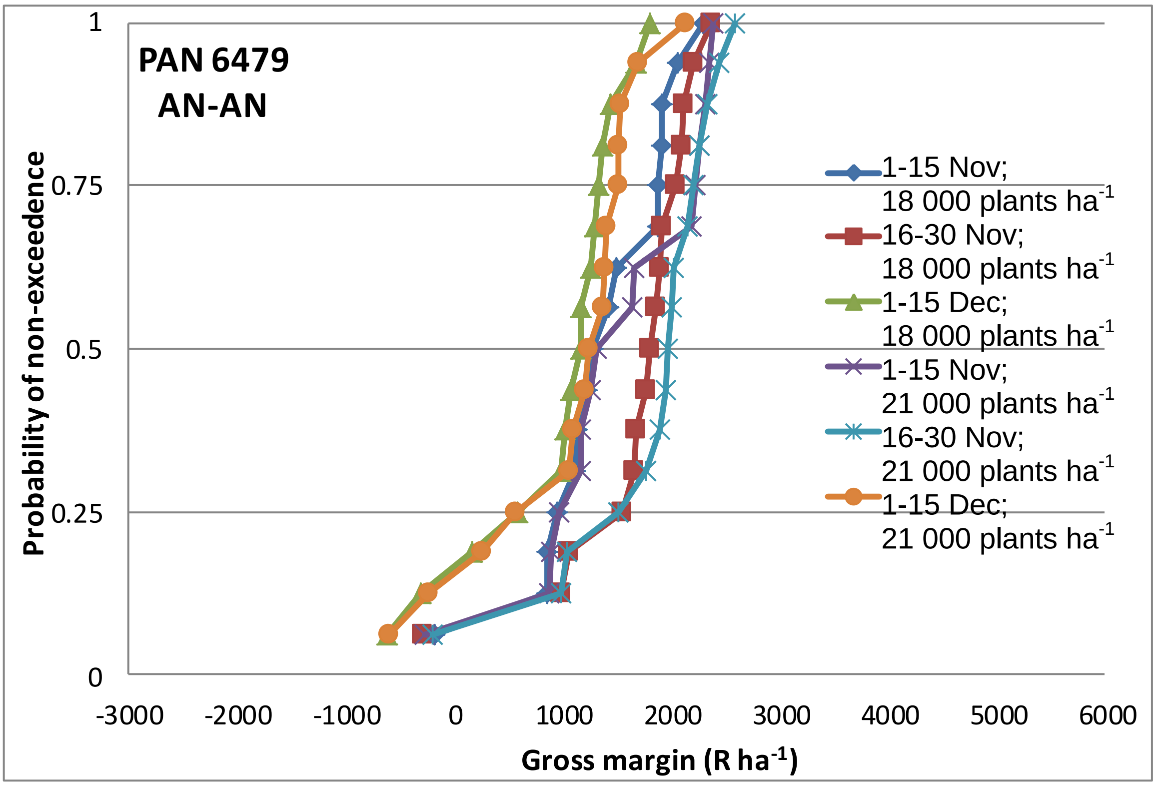


Figure 4.52: Cumulative distribution function of long-term gross margins for PAN 6479 associated with 3 different planting dates and 2 different plant population densities during AN-AN rainfall conditions (using a fertiliser application rate of 50 kg ha^{-1} N and weeding twice).

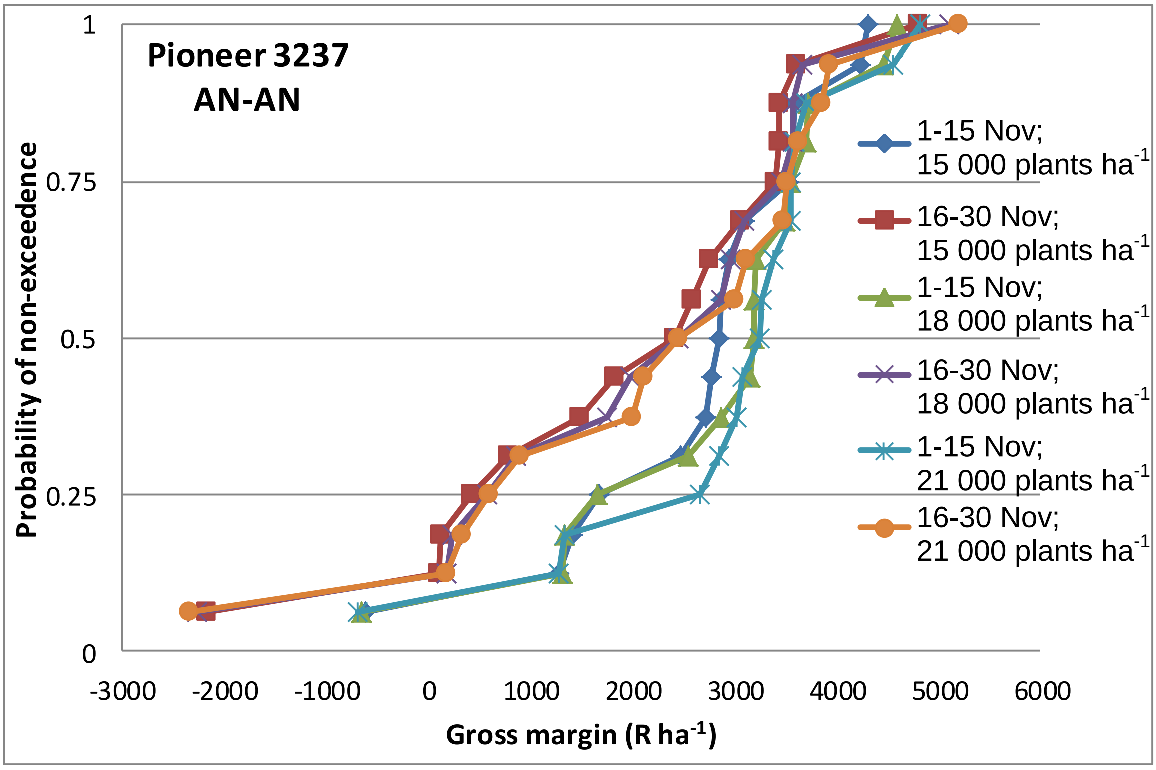


Figure 4.53: Cumulative distribution function of long-term gross margins for Pioneer 3237 associated with 2 different planting dates and 3 different plant population densities during AN-AN rainfall conditions (using a fertiliser application rate of 75 kg ha^{-1} N and weeding twice).

For PAN 6479, the best planting date was 16-30 November. At the 50% probability of non-exceedence the gross margins under a plant population density of 21 000 plants ha^{-1} planted during 16-30 November was R1 972 ha^{-1} compared to R1 322 ha^{-1} and R1 248 ha^{-1} when planted during 1-15 November and 1-15 December, respectively (Figure 4.52). The field costs for using a plant population density of 21 000 plants ha^{-1}, weeding twice and fertiliser application rate of 50 kg ha^{-1} N was R1 798 ha^{-1}. An additional profit of R650 ha^{-1} could be realised when opting to plant during 16-30 November as opposed to 1-15 November. Under optimum planting date (16-30 November), there was a 75% probability that the gross margin will not exceed R2 208 ha^{-1} and R2 045 ha^{-1} under 21 000 and 18 000 plants ha^{-1}, respectively. Their corresponding field costs were R1 798 ha^{-1} and R1 748 ha^{-1}, respectively. The difference in field costs between these two management practices was R50 ha^{-1}, thus using 21 000 plants ha^{-1} instead of 18 000 plants ha^{-1} a farmer could obtain an additional R163 ha^{-1}.

For Pioneer 3237, the profit could be maximised by planting earlier under an optimum weeding frequency and fertiliser application rate. At the 50% probability of non-exceedence the gross margins for 1-15 November and 16-30 November were R3 253 ha^{-1} and R2 468 ha^{-1}, respectively (Figure 4.53). This was under a plant population density of 21 000 plants ha^{-1}, optimum fertiliser application rate of 75 kg ha^{-1} N and weeding twice. The difference in profit between planting during 1-15 November and 16-30 November was approximately R785 ha^{-1}. Planting after 15 November would significantly decrease the profit. The most profitable management practice, given an optimum weeding frequency and fertiliser application rate, involved maximising the plant population density (Figure 4.53). At a 25% probability of non-exceedence, the gross margins for planting maize during 1-15 November was R2 675 ha^{-1} when using 21 000 plants ha^{-1} compared to R1 665 ha^{-1} and R1 689 when using 18 000 and 15 000 plants ha^{-1}, respectively. Their respective field cost were R2 338 ha^{-1}, R2 265 ha^{-1} and R2 191 ha^{-1}. The difference in field cost between 21 000 and 15 000 plants ha^{-1} was R73 ha^{-1}, while an additional R1 010 ha^{-1} could be made from the higher plant population density. This indicated that by using higher plant population density (21 000 plants ha^{-1}) would lead to significant increase in profit.

4.4.3 Economic analysis of above-normal followed by near-normal (AN-NN) rainfall conditions

Combinations of yield predictors subjected to the economic analyses are provided in Table A3 for PAN 6479 and Table A4 for Pioneer 3237 (Appendix A). The economic benefits associated with each set of management practices are shown in Tables B3 and B4 (Appendix B) for PAN 6479 and Pioneer 3237, respectively. In section 4.3.3 it was shown that weeding frequency was the most significant management practice for PAN 6479, while plant population density was the least. For Pioneer 3237, the most significant management practice was choice of planting date, while the least management practice was plant population density (Table 4.4). From Table B3 (Appendix B) it is evident that the optimum fertiliser application rate was 35 kg ha^{-1} N, while the best planting date was 16-30 November for PAN 6479. For Pioneer 3237, the optimum fertiliser application rate was 75 kg ha^{-1} N, while the optimum weeding frequency was 3 times (Table B4, Appendix B).

Economic analysis of the different sets of management practices showed that with PAN 6479 a close relationship existed between weeding frequencies and plant population densities at the best determined plant date and optimum fertiliser application rate. For Pioneer 3237 a close relationship existed between different planting dates and plant population densities (see Appendix B). For PAN 6479, the weeding frequencies 1 and 2 times contributed to the higher maize yields, while the plant population densities that maximised yields were at 15 000, 18 000 and 21 000 plants ha^{-1} (Table B3). For Pioneer 3237, the planting dates that contributed to higher maize yields were 1-15 November, 16-30 November and 1-15 December, while plant population densities of 9 000 and 12 000 plants ha^{-1} resulted in higher maize yields than 15 000, 18 000 and 21 000 plants ha^{-1} (Table B4). This observation was somewhat concerning as one would naturally expect higher plant population densities to perform better under such good rainfall conditions. The CDFs in Figure 4.54 illustrate the economic benefit associated with three plant population densities and two weeding frequencies for PAN 6479. Figure 4.55 illustrates the economic benefit associated with three different planting dates and two plant population densities for Pioneer 3237 during AN-NN rainfall conditions.

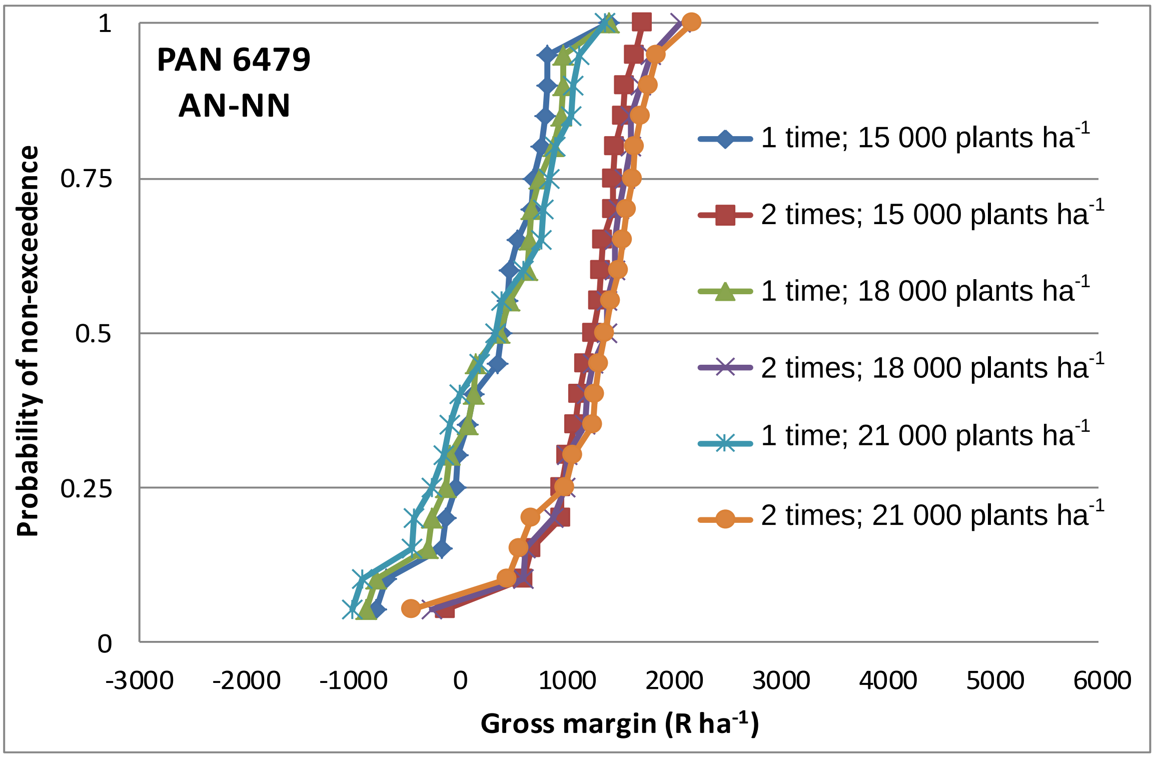


Figure 4.54: Cumulative distribution function of long-term gross margins for PAN 6479 associated with 3 different plant population densities and 2 weeding frequencies during AN-NN rainfall conditions (using a fertiliser application rate of 35 kg ha^{-1} N and planted during 16-30 November).

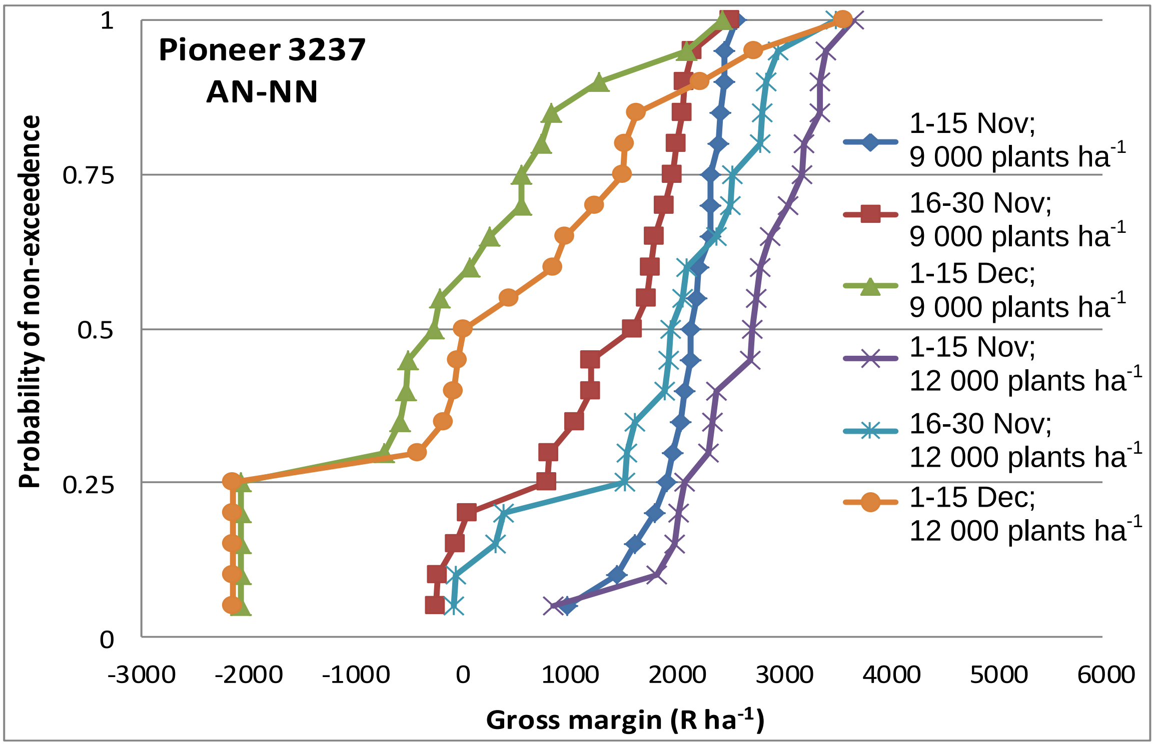


Figure 4.55: Cumulative distribution function of long-term gross margins for Pioneer 3237 associated with 3 different planting dates and 2 plant population densities during AN-NN rainfall conditions (using a fertiliser application rate of 75 kg ha^{-1} N and weeding thrice).

For PAN 6479, at the 50% probability of non-exceedence the gross margins for weeding frequencies one and two times under a plant population density of 15 000 plants ha^{-1} were R395 ha^{-1} and R1 254 ha^{-1}, respectively (Figure 4.54). Their respective field costs were R1 449 ha^{-1} and R1 473 ha^{-1}. An additional profit of R859 ha^{-1} could be obtained when weeding twice instead of once, while spending only R24 ha^{-1} extra on field costs. The most profitable management practices, given at an optimum fertiliser application rate and weeding frequency, involved maximising the plant population density. There is a 75% probability that the gross margin will not exceed R1 455 ha^{-1}, R1 561 ha^{-1} and R1 636 ha^{-1} under plant population densities of 15 000, 18 000 and 21 000 plants ha^{-1}, respectively. The respective field costs were R1 473 ha^{-1}, R1 523 ha^{-1} and R1 573 ha^{-1}. The difference in profit between 21 000 and 15 000 plants ha^{-1} was R181 ha^{-1}, while an additional R100 ha^{-1} was spend on field costs.

For Pioneer 3237 (Figure 4.55), the profit could be maximised by planting earlier under an optimum weeding frequency and fertiliser application rate. At the 50% probability of non-exceedence the gross margins for planting during 1-15 November, 16-30 November and 1-15 December under a plant population density of 9 000 plants ha^{-1} were R2 143 ha^{-1}, R1 599 ha^{-1} and -R258 ha^{-1}, respectively. The difference in profit between planting during 1-15 November and 1-15 December was R2 401 ha^{-1}. This clearly indicates that the best planting date for Pioneer 3237 was 1-15 November. The most profitable management practices involved optimising the plant population density under the best planting date. The gross margins using plant population densities of 9 000 and 12 000 plants ha^{-1} were R2 334 ha^{-1} and R3 182 ha^{-1}, respectively at the 75% probability of non-exceedence level. The respective field costs were R2 069 ha^{-1} and R2 142 ha^{-1}, while the difference in profit between 12 000 and 9 000 plants ha^{-1} was R848 ha^{-1}. Thus, the optimum plant population density for Pioneer 3237 was 12 000 plants ha^{-1}.

4.4.4 Economic analysis of above-normal followed by below-normal (AN-BN) rainfall conditions

Yield predictor combinations subjected to the economic analysis are provided in Tables A5 and A6 for PAN 6479 and Pioneer 3237, respectively (Appendix A). The economic benefits associated with each set of management practices are shown in Table B5 for PAN 6479 and Table B6 for Pioneer 3237 (Appendix B).

In section 4.3.4 it was shown that the weeding frequency was the most significant management practice for PAN 6479, while the plant population density was the least significant. For Pioneer 3237, the most significant management practice was planting date, with fertiliser application rate being the least (Table 4.5). It is evident from the data presented in Table B5 (Appendix B) that the optimum fertiliser application rate was 35 kg ha^{-1} N, while the best planting date was 16-30 November for PAN 6479. For Pioneer 3237, the optimum plant population density was 9 000 plants ha^{-1}, while the optimum weeding frequency was 3 times.

The economic analysis of the different sets of management practices showed that at an optimum planting date and fertiliser application rate a close relationship existed between weeding frequencies and plant population densities for PAN 6479. For Pioneer 3237 a close relationship existed between planting dates and fertiliser application rates with optimum weeding frequency and plant population density (Appendix B). For PAN 6479, the highest yielding weeding frequencies were 1 and 2 times, while the plant population densities that provided the highest maize yields were 9 000, 12 000 and 15 000 plants ha^{-1} (Table B5). For Pioneer 3237, the planting dates that contributed most to maize yields were 1-15 November and 16-30 November, while fertiliser application rates of 35, 50 and 75 kg ha^{-1} N provided more profitable maize yields than 0 and 100 kg ha^{-1} N (see Table B6). The CDF in Figure 4.56 (PAN 6479) illustrate the economic benefit under three different plant population densities and two weeding frequencies using optimum planting date and fertiliser application rate. The CDF in Figure 4.57 (Pioneer 3237) illustrate the economic benefit under two different planting dates and three fertiliser application rates during AN-BN rainfall season.

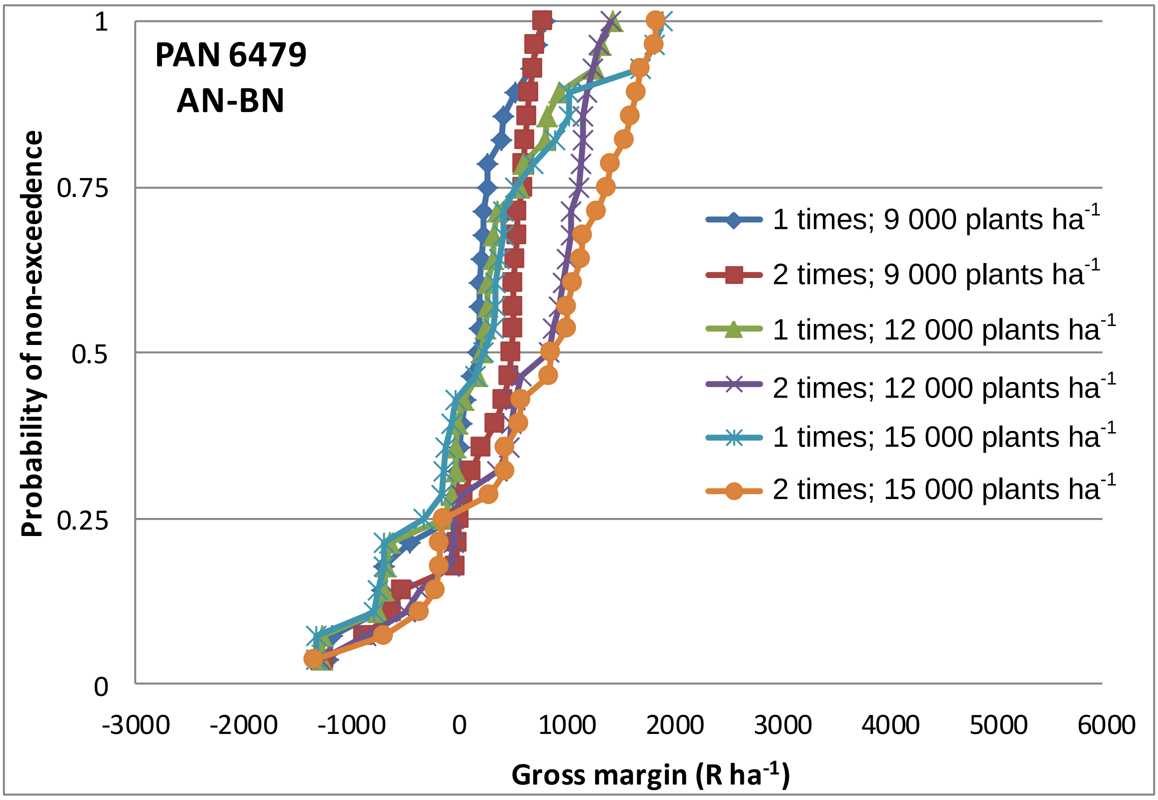


Figure 4.56: Cumulative distribution function of long-term gross margins for PAN 6479 associated with 3 different plant population densities and 2 weeding frequencies during AN-BN rainfall conditions (using a fertiliser application rate of 35 kg ha^{-1} N and planted during 16-30 November).

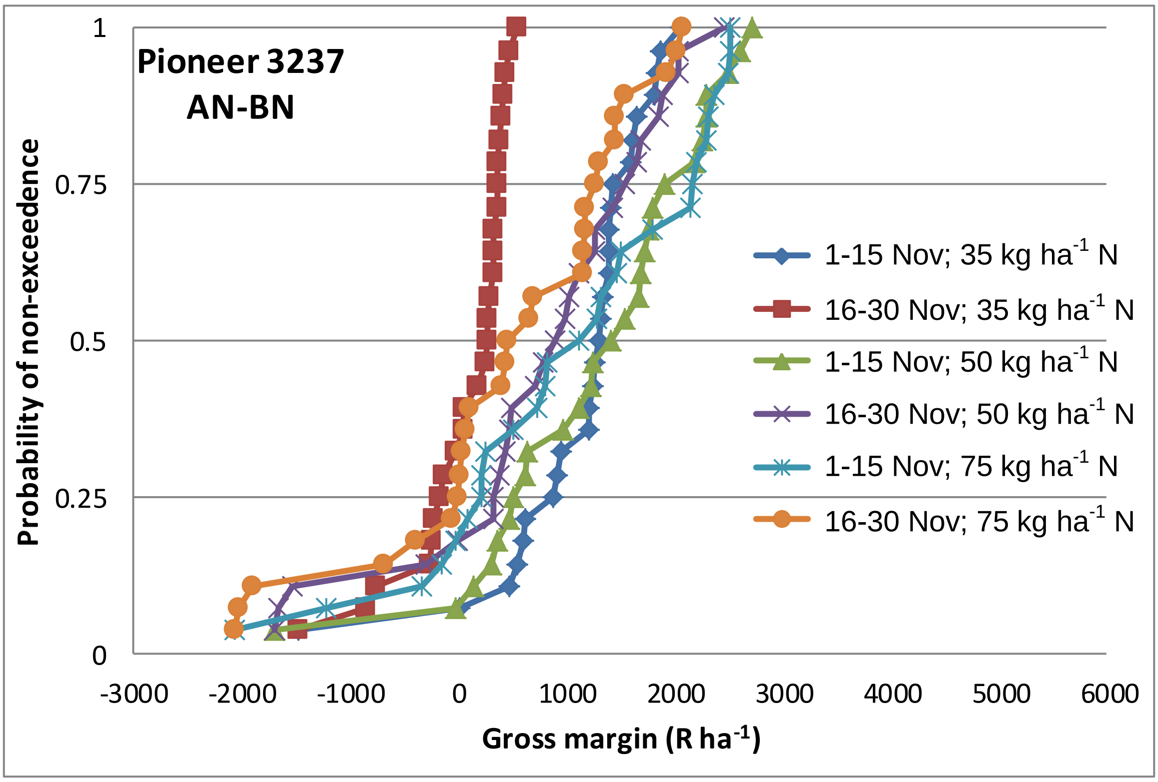


Figure 4.57: Cumulative distribution function of long-term gross margins for Pioneer 3237 associated with 2 different planting dates and 3 fertiliser application rates during AN-BN rainfall conditions (using a plant population density of 9 000 plants ha^{-1} and weeding thrice).

For PAN 6479 the most profitable management practices, given an optimum fertiliser application rate and best planting date, involved optimising the weeding frequency. At the 50% probability of non-exceedence level the gross margins using a plant population density of 12 000 plants ha^{-1} are R216 ha^{-1} and R853 ha^{-1} for weeding once and twice, respectively (Figure 4.56). Their respective field costs were R1 400 ha^{-1} and R1 424 ha^{-1}. An additional R637 ha^{-1} could be obtained when weeding twice as opposed to once, while spending an extra R24 ha^{-1} on field costs. Profit could also be maximised by optimising the plant population density under an optimum weeding frequency and fertiliser application rates. There was a 75% probability that the gross margin would not exceed R602 ha^{-1}, R1 121 ha^{-1} and R1 394 ha^{-1} when weeding twice and using plant population densities of 9 000, 12 000 and 15 000 plants ha^{-1}, respectively. The respective field costs were R1 374 ha^{-1}, R1 424 ha^{-1} and R1 473 ha^{-1}. The difference in profit between 15 000 and 9 000 plants ha^{-1} was R792 ha^{-1}, while the additional field cost was R99 ha^{-1}. Thus, the optimum population density for PAN 6479 was 15 000 plants ha^{-1}.

A substantial profit could be attained by planting Pioneer 3237 earlier under an optimum weeding frequency and plant population density. At the 50% probability of non-exceedence the gross margins for planting during 1-15 November and 16-30 November under a fertiliser application rate of 35 kg ha^{-1} N were R1 298 ha^{-1} and R278 ha^{-1}, respectively (Figure 4.57). An additional R1 010 ha^{-1} could be made when opting to plant during 1-15 November as opposed to 16-30 November. There was a 75% probability that the gross margin would not exceed R1 434 ha^{-1}, R1 915 ha^{-1} and R2 166 ha^{-1} with fertiliser application rates of 35, 50 and 75 kg ha^{-1} N, respectively. The respective field costs were R1 469 ha^{-1}, R1 694 ha^{-1} and R2 069 ha^{-1}. An additional R732 ha^{-1} could be attained when using 75 kg ha^{-1} N as opposed to 35 kg ha^{-1} N, while spending an additional R600 ha^{-1}. The results also indicated that a farmer could obtain an additional profit of R251 ha^{-1} when using 75 kg ha^{-1} N compared to 50 kg ha^{-1} N, while spending an extra R375 ha^{-1} on field costs. The difference in profit between fertiliser application rates of 35 and 50 kg ha^{-1} N was R381 ha^{-1}, while the difference in field cost was R225 ha^{-1}. Fertiliser application rates above 50 kg ha^{-1} N could lead to a negligible increase in profit.

4.4.5 Economic analysis of near-normal followed by above-normal (NN-AN) rainfall conditions

The combinations of yield predictors that were subjected to the economic analysis are provided in Table A7 for PAN 6479 and Table A8 for Pioneer 3237 (Appendix A). The economic benefits associated with each set of management practices are shown in Table B7 for PAN 6479 and Table B8 for Pioneer 3237 (Appendix B).

In section 4.3.5 it was shown that the choice of planting date was the most significant management practice, while plant population density was the least significant for both cultivars. From Table B7 it is evident that the optimum fertiliser application rate for PAN 6479 was 50 kg ha^{-1} N, while the optimum weeding frequency was 2 times. For Pioneer 3237, (Table B8) the optimum fertiliser application rate was 75 kg ha^{-1} N, while the optimum weeding frequency was 3 times.

Economic analysis of the different sets of management practices indicated that with an optimum fertiliser application rate and weeding frequency a close relationship existed between the different planting dates and plant population densities for both cultivars (see Appendix B). For PAN 6479, planting dates 1-15 November, 16-30 November and 1-15 December produced higher yields than 16-30 December and 1-15 January, while the plant population densities that maximised yields were 15 000 and 21 000 plants ha^{-1} (Table B7). For Pioneer 3237 the planting dates that contributed more to maize yields are 1-15 November, 16-30 November and 1-15 December, while plant population densities of 12 000 and 18 000 plants ha^{-1} yielded more than 9 000, 15 000 and 21 000 plants ha^{-1} (Table B8). The CDFs in Figures 4.58 and 4.59 illustrate the economic benefits associated with three different planting dates and two plant population densities during NN-AN rainfall conditions for PAN 6479 and Pioneer 3237, respectively.

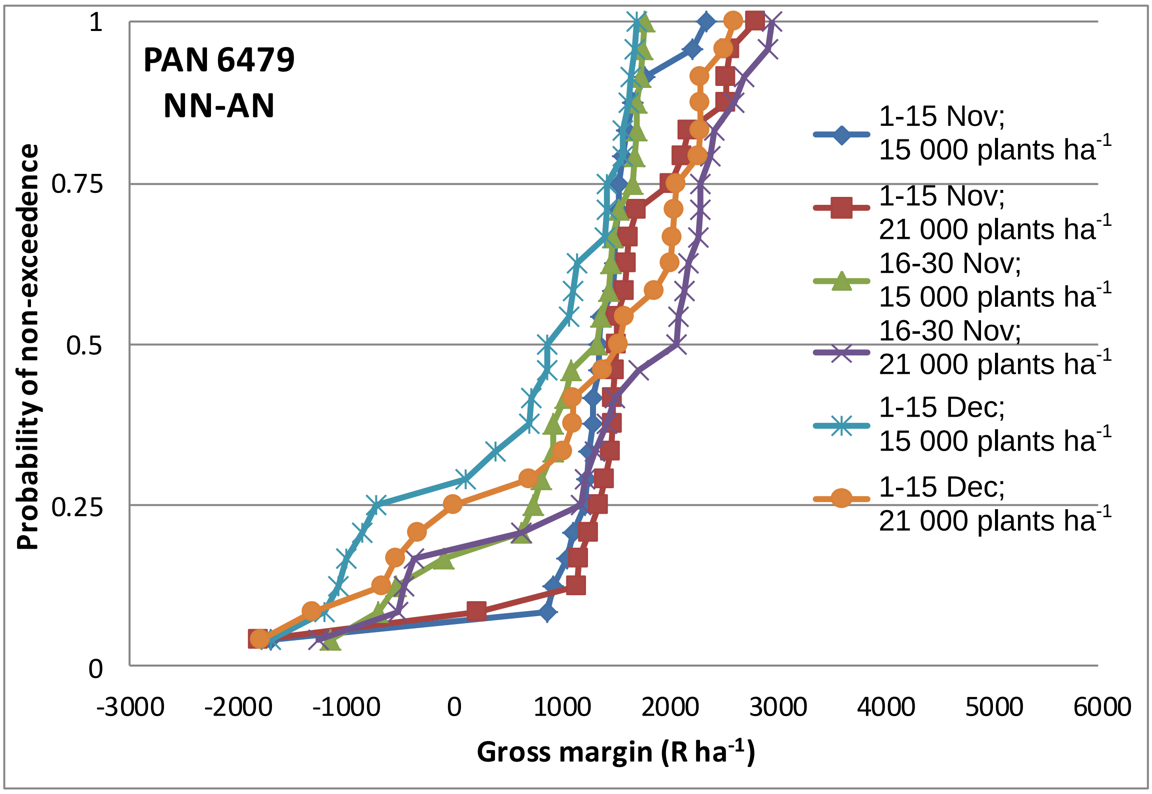


Figure 4.58: Cumulative distribution function of long-term gross margins for PAN 6479 associated with 3 different planting dates and 2 plant population densities during NN-AN rainfall conditions (using a fertiliser application rate of 50 kg ha^{-1} N and weeding twice).

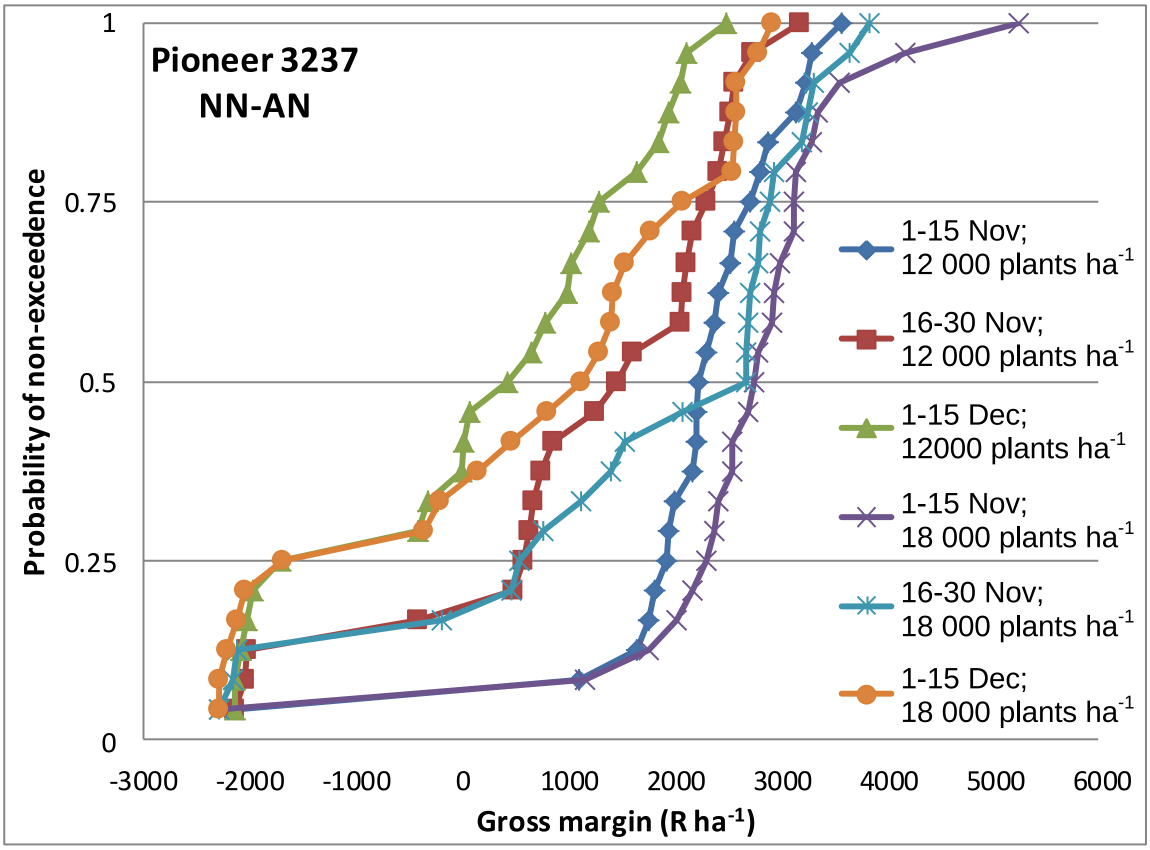


Figure 4.59: Cumulative distribution function of long-term gross margins for Pioneer 3237 associated with 3 different planting dates and 2 plant population densities during NN-AN rainfall conditions (using a fertiliser application rate of 75 kg ha^{-1} N and weeding thrice).

For PAN 6479 (Figure 4.58) there was a 50% probability that the gross margins for planting during 1-15 November, 16-30 November and 1-15 December at a plant population density of 21 000 plants ha^{-1} would not exceed R1 526 ha^{-1}, R2 086 ha^{-1} and R1 545 ha^{-1}, respectively. The difference in profit between planting 1-15 November and 1-15 December was R560 ha^{-1}, while the difference between 1-15 November and 16-30 November was R541 ha^{-1}. Therefore, the best planting date for PAN 6479 was 16-30 November. There was a 75% probability that the gross margin would not exceed R1 664 ha^{-1} and R2 298 ha^{-1} when planted during 16-30 November at plant population density of 15 000 and 21 000 plants ha^{-1}, respectively. The respective field costs were R1 699 ha^{-1} and R1 798 ha^{-1}. An additional profit of R634 ha^{-1} could be attained when using 21 000 plants ha^{-1} instead of 15 000 plants ha^{-1}, while spending an additional R98 ha^{-1} on field cost. These results clearly show that the optimum plant population density for PAN 6479 was 21 000 plants ha^{-1}.

For Pioneer 3237, the profit could be maximised by planting earlier under an optimum weeding frequency and fertiliser application rates. At the 50% probability of non-exceedence the gross margins for planting during 1-15 November, 16-30 November and 1-15 December under 12 000 plants ha^{-1} were R2 230 ha^{-1}, R1 455 ha^{-1} and R429 ha^{-1}, respectively (Figure 4.59). An additional R1 801 ha^{-1} could be made when opting to plant during 1-15 November as opposed to 1-15 December. An additional profit of R775 ha^{-1} could also be made when opting to plant during 1-15 November as opposed to 16-30 November. Therefore, the best planting date for Pioneer 3237 was 1-15 November. There was a 75% probability that the gross margin will not exceed R2 722 ha^{-1} and R3 133 ha^{-1} for planting during 1-15 November at plant population densities of 12 000 and 18 000 plants ha^{-1}, respectively. The respective field costs were R2 142 ha^{-1} and R2 289 ha^{-1}. The difference in profit between 18 000 and 12 000 plants ha^{-1} was R411 ha^{-1}, while spending an additional R147 ha^{-1} on field costs. Thus, the optimum plant population density for Pioneer 3237 was 18 000 plants ha^{-1}.

4.4.6 Economic analysis of near-normal followed by near-normal (NN-NN) rainfall conditions

The combinations of yield predictors that were subjected to the economic analysis are provided in Table A9 for PAN 6479 and Table A10 for Pioneer 3237 (Appendix A). The economic benefits associated with each set of management practices are shown in Table B9 for PAN 6479 and Table B10 for Pioneer 3237 (Appendix B).

The significance test for contribution of predictors to maize yields presented in section 4.3.6 showed that weeding frequency was the most significant management practice for PAN 6479, while plant population density was the least significant. For Pioneer 3237, the most significant management practice was the planting date, while plant population density was the least significant (Table 4.7). From the data presented in Table B9 it is evident that the optimum fertiliser application rate was 35 kg ha^{-1} N, while the best planting date was 1-15 November for PAN 6479. For Pioneer 3237, (Table B10) the optimum fertiliser application rate was 75 kg ha^{-1} N, while the optimum weeding frequency was 2 times.

Economic analysis of the different sets of management practices under optimum planting date and fertiliser application rate revealed a close relationship between the weeding frequency and plant population density for PAN 6479 (Appendix B). For Pioneer 3237 a close relationship existed between the different planting dates and fertiliser application rates under optimum weeding frequency and plant population density (see Table B10). For PAN 6479 the weeding frequencies that contributed most to maize yields were 1 and 2 times, while the plant population densities of 9 000, 12 000 and 15 000 plants ha^{-1} produce profitable maize yield. For Pioneer 3237, the planting dates that dominated the contribution to maize yield were 1-15 November and 16-30 November, while plant population densities of 9 000, 15 000 and 21 000 plants ha^{-1} resulted in highest yields. The CDFs in Figure 4.60 illustrate the economic benefit associated with two different weeding frequencies and three plant population densities for PAN 6479. Figure 4.61 illustrates the CDFs of the economic benefit associated with two different planting dates and three fertiliser application rates for Pioneer 3237.

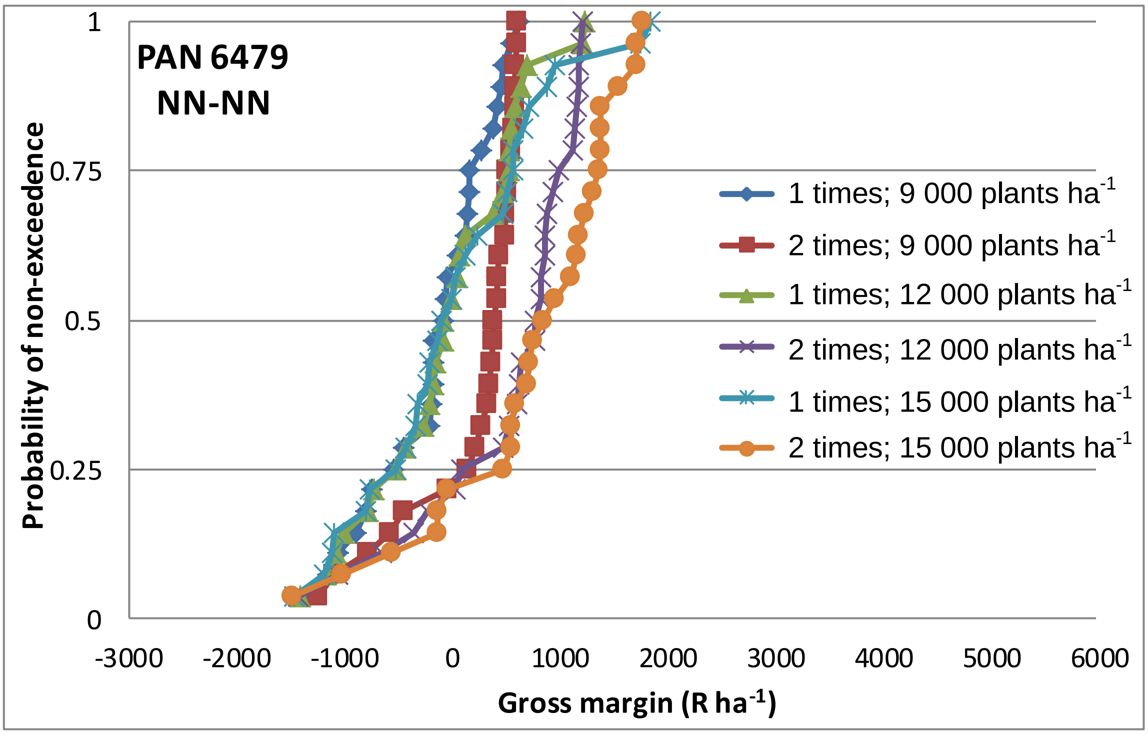


Figure 4.60: Cumulative distribution function of long-term gross margins for PAN 6479 associated with 3 different plant population densities and 2 weeding frequencies during NN-NN rainfall conditions (using a fertiliser application rate of 35 kg ha^{-1} N and planted during 1-15 November).

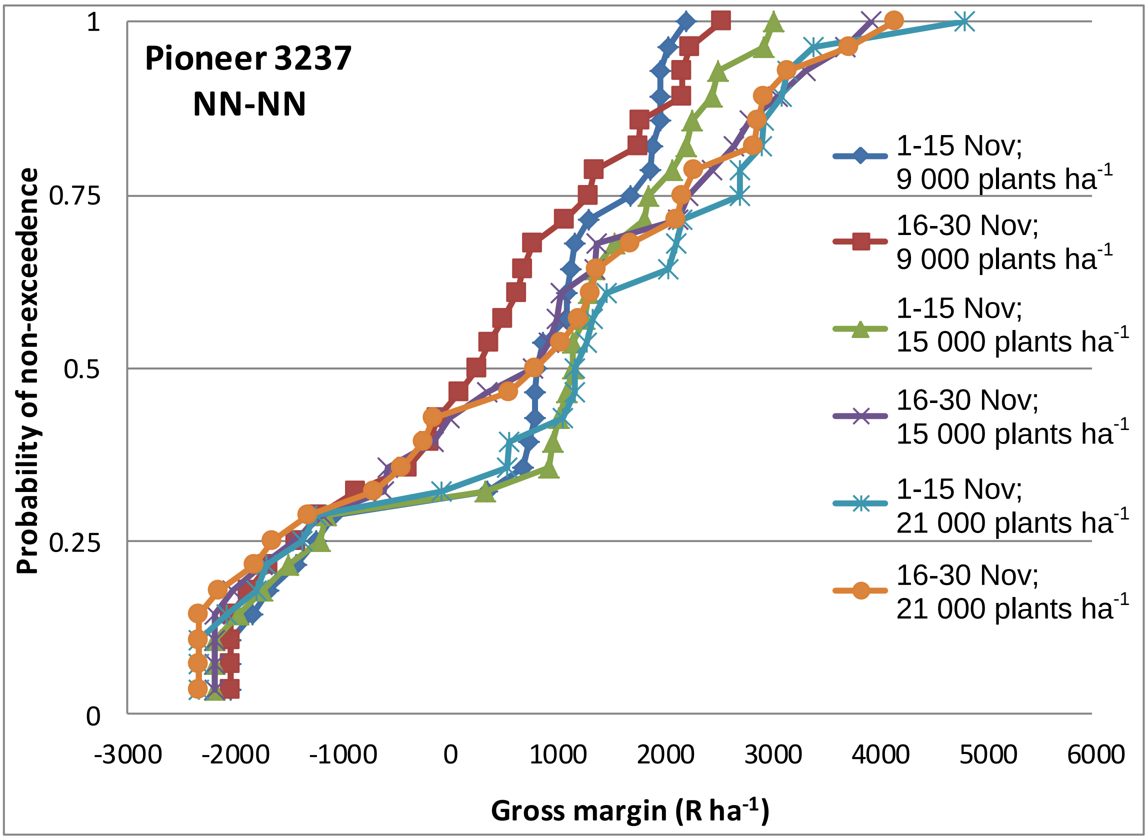


Figure 4.61: Cumulative distribution function of long-term gross margins for Pioneer 3237 associated with 2 different planting dates and 3 plant population densities during NN-NN rainfall conditions (using a fertiliser application rate of 75 kg ha^{-1} N and weeding twice).

At the 50% probability of non-exceedence, the gross margins for using weeding frequencies of 1 and 2 times at a plant population density of 15 000 plants ha^{-1} were R704 ha^{-1} and R1 683 ha^{-1}, respectively for PAN 6479 (Figure 4.60). Their respective field costs were -R62 ha^{-1} and R786 ha^{-1}. A difference in profit between weeding twice and once was R848 ha^{-1} and the field costs difference was R24 ha^{-1}. During these seasonal rainfall conditions, with no weeding or weeding once financial losses will occur. The profit could also be increased by optimising the plant population density. There was a 75% probability that the gross margin will not exceed R755 ha^{-1}, R1 280 ha^{-1} and R2 006 ha^{-1} when weeding twice at plant population densities of 9 000, 12 000 and 15 000 plants ha^{-1}, respectively. The respective field costs were R1 374 ha^{-1}, R1 424 ha^{-1} and R1 473 ha^{-1}. The difference in profit between 12 000 and 15 000 plants ha^{-1} was R726 ha^{-1}, while spending only an additional R42 ha^{-1} on field costs.

The most profitable management practices, given an optimum fertiliser application rate and weeding frequency, involved early planting dates for Pioneer 3237. At the 50% probability of non-exceedence the gross margins for maize planted during 1-15 November and 16-30 November at a plant population density of 9 000 plants ha^{-1} were R829 ha^{-1} and R258 ha^{-1}, respectively (Figure 4.61). The farmer could gain an additional profit of R571 ha^{-1} when opting to plant during 1-15 November as opposed to 16-30 November. The gross margins for 15 000 plants ha^{-1} planted during 1-15 November and 16-30 December were R1 154 ha^{-1} and R782 ha^{-1}, respectively. There was a 75% probability that the gross margin will not exceed R1 688 ha^{-1}, R1 866 ha^{-1} and R2 708 ha^{-1} at plant population densities of 9 000, 15 000 and 21 000 plants ha^{-1}, respectively. The respective field costs were R2 045 ha^{-1}, R2 191 ha^{-1} and R2 338 ha^{-1}. The difference in profit between 21 000 and 9 000 plants ha^{-1} was R1 020 ha^{-1}, while an extra R293 ha^{-1} was spend on field costs. The optimum plant population density was 21 000 plants ha^{-1}, while the best planting date was 1-15 November.

4.4.7 Economic analysis of near-normal followed by below-normal (NN-BN) rainfall conditions

The combinations of yield predictors that were subjected to the economic analysis are summarised in Table A11 for PAN 6479 and Table A12 for Pioneer 3237 (Appendix A). The economic benefits associated with each set of management practices are shown in Table B11 for PAN 6479 and Table B12 for Pioneer 3237 (Appendix B). In section 4.3.7 it was shown that weeding frequency was the most significant management practice for PAN 6479, while plant population density was the least significant. For Pioneer 3237, the most significant management practice was planting date, while the least significant was fertiliser application rate (Table 4.3.7). From the data presented in Table B11 (Appendix B) it is evident that the optimum fertiliser application rate was 35 kg ha^{-1} N, while the best planting date was 16-30 November for PAN 6479. For Pioneer 3237, the results presented in Table B12 (Appendix B) indicated that the optimum plant population density was 9 000 plants ha^{-1}, while the optimum weeding frequency was 3 times.

Economic analysis of the different sets of management practices showed that at an optimum planting date and fertiliser application rate a close relationship existed between weeding frequency and plant population density for PAN 6479. For Pioneer 3237 a close relationship existed between different planting dates and fertiliser application rates at an optimum weeding frequency and plant population density (see Appendix B). For PAN 6479, the weeding frequencies that contributed most to maize yields were once and twice, while the plant population densities that provided the highest maize yield were 9 000, 12 000 and 15 000 plants ha^{-1}. For Pioneer 3237, planting dates that dominated the contribution to maize yield were 1-15 November and 16-30 November, while fertiliser application rates of 35, 50 and 75 kg ha^{-1} N provided significantly high maize yields than 0 and 100 kg ha^{-1} N. The CDFs in Figure 4.62 illustrate the economic benefit associated with two different weeding frequencies and three plant population densities during NN-BN rainfall conditions for PAN 6479. Figure 4.63 illustrates the CDFs of the economic benefit associated with two different planting dates and three fertiliser application rates during NN-BN rainfall conditions for Pioneer 3237, respectively.

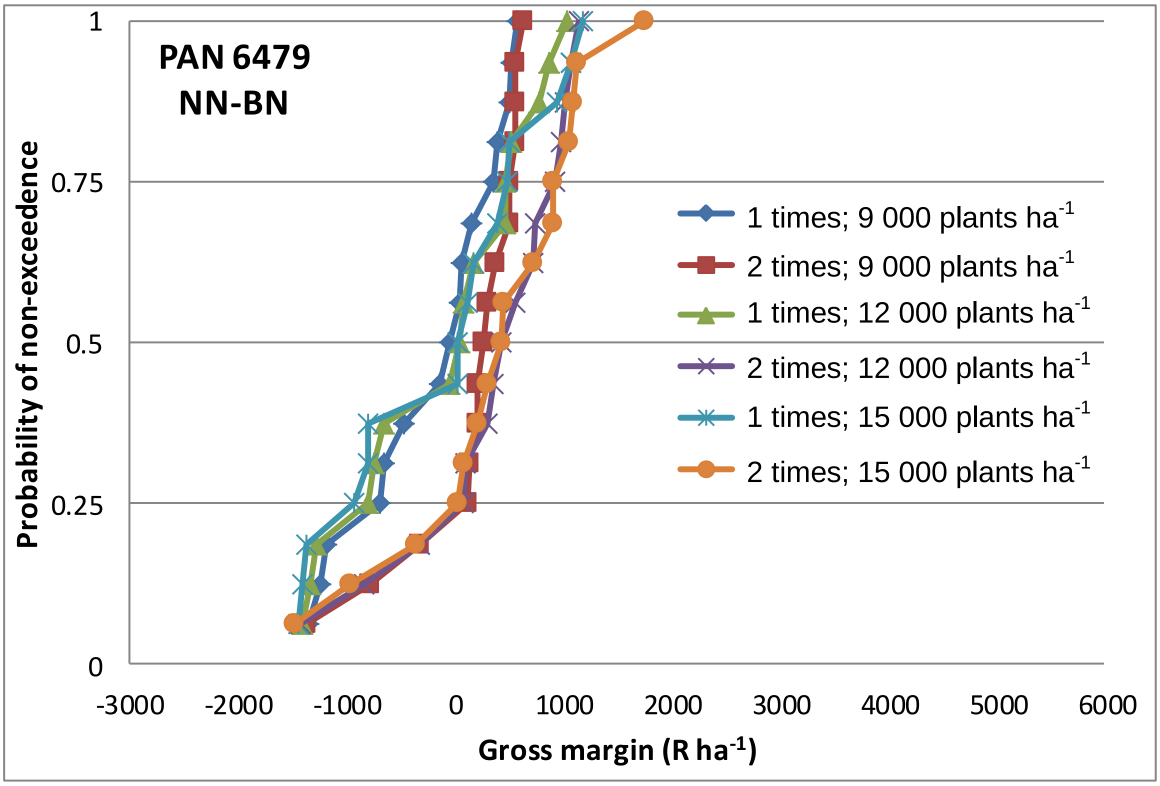


Figure 4.62: Cumulative distribution function of long-term gross margins for PAN 6479 associated with 3 different plant population densities and 2 weeding frequencies during NN-BN rainfall conditions (using a fertiliser application rate of 35 kg ha^{-1} N and planted during 16-30 November).

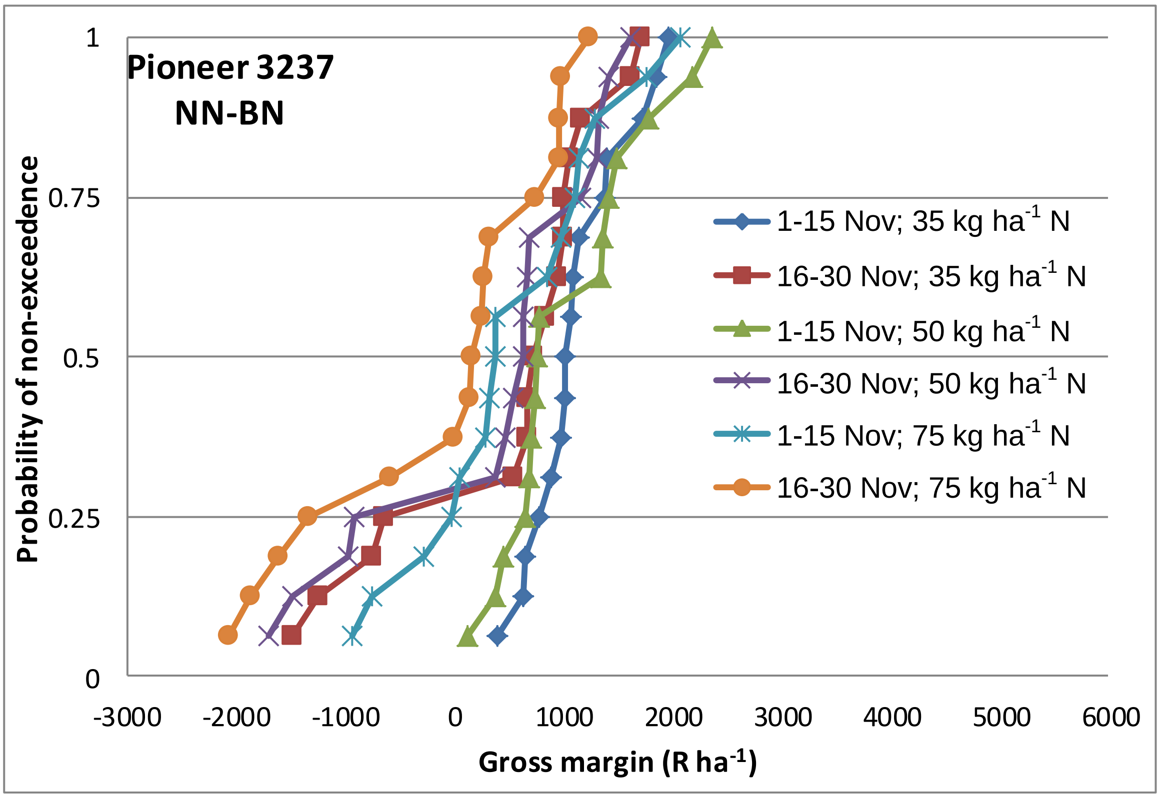


Figure 4.63: Cumulative distribution function of long-term gross margins for Pioneer 3237 associated with 2 different planting dates and 3 fertiliser application rates during NN-BN rainfall conditions (using a plant population density of 9 000 plants ha^{-1} and weeding thrice).

For PAN 6479 (Figure 4.62) at 50% probability of non-exceedence, the gross margins for 15 000 plants ha^{-1} when weeding once and twice were R27 ha^{-1} and R429 ha^{-1}, respectively. The respective field costs were R1 449 ha^{-1} and R1 473 ha^{-1}. An additional profit of R402 ha^{-1} could be obtained when weeding twice compared to once, while spending an extra R24 ha^{-1}. During these seasonal rainfall conditions, the optimum plant population density was 12 000 plants ha^{-1}. There was a 75% probability that the gross margin will not exceed R505 ha^{-1}, R934 ha^{-1} and R919 ha^{-1} at a weeding frequency of 2 times using plant population densities of 9 000, 12 000 and 15 000 plants ha^{-1}, respectively. The respective field costs were R1 374 ha^{-1}, R1 424 ha^{-1} and R1 473 ha^{-1}. The difference in profit between 9 000 and 12 000 plants ha^{-1} was R429 ha^{-1}, while spending an extra R42 ha^{-1} on field costs.

At the 50% probability of non-exceedence the gross margins for planting Pioneer 3237 during 1-15 November and 16-30 November at a fertiliser application rate of 35 kg ha^{-1} N were R1 025 ha^{-1} and R737 ha^{-1}, respectively (Figure 4.63). An additional profit of R288 ha^{-1} could be made when opting to plant during 1-15 November as opposed to 16-30 November. The gross margins for planting during 1-15 November and 16-30 November at 50 kg ha^{-1} N were R759 ha^{-1} and R639 ha^{-1}, respectively. Therefore the best planting date for Pioneer 3237 was 1-15 November. Profit could also increase by optimising fertiliser application rate (Figure 4.63). There was a 75% probability that the gross margin would not exceed R1 395 ha^{-1}, R1 432 ha^{-1} and R1 107 ha^{-1} using a planting date of 1-15 November at fertiliser application rates of 35, 50 and 75 kg ha^{-1} N, respectively. The respective field costs were R1 469 ha^{-1}, R1 694 ha^{-1} and R2 069 ha^{-1}. The difference in profit between 35 and 50 kg ha^{-1} N was R37 ha^{-1}, while spending an additional R225 ha^{-1}. Farmers could obtain an additional profit of R288 ha^{-1} when opting to use 35 kg ha^{-1} N as opposed to 75 kg ha^{-1} N, while spending R600 ha^{-1} less on field costs. Thus, the optimum fertiliser application rate was 35 kg ha^{-1} N.

4.4.8 Economic analysis of below-normal followed by above-normal (BN-AN) rainfall conditions

Yield predictor combinations subjected to economic analysis are summarised in Tables A13 and A14 (Appendix A) for PAN 6479 and Pioneer 3237, respectively. The economic benefits associated with each set of management practices are shown in Tables B13 and B14 (Appendix B) for PAN 6479 and Pioneer 3237, respectively.

It was shown in section 4.3.8 that fertiliser application rate was the most significant management practice for PAN 6479, while plant population density was the least. For Pioneer 3237, the most significant management practice was the planting date, while plant population density was also the least significant (Table 4.9). From Table B13 it is evident that the optimum weeding frequency was 2 times, while the best planting date was 1-15 November for PAN 6479. For Pioneer 3237 Table B14 indicated that the optimum fertiliser application rate was 75 kg ha^{-1} N, while the optimum weeding frequency was 3 times.

Economic analysis of the different sets of management practices revealed a close relationship between the different fertiliser application rates and plant population densities for PAN 6479 under optimum weeding frequency and planting date. For Pioneer 3237 at an optimum fertiliser application rate and weeding frequency a close relationship was revealed between the different planting dates and plant population densities (Appendix B). For PAN 6479 fertiliser application rates of 35 and 50 kg ha^{-1} N contributed more to maize yields than 0, 75 and 100 kg ha^{-1} N, while plant population densities of 12 000, 15 000 and 21 000 plants ha^{-1} maximised yield. For Pioneer 3237 planting dates that contributed more to maize yields were 1-15 November and 16-30 November, while plant population densities of 18 000 and 21 000 plants ha^{-1} provided higher yields than 9 000, 12 000 and 15 000 plants ha^{-1}. The CDFs in Figure 4.64 illustrates the economic benefit associated with three plant population densities and two fertiliser application rates for PAN 6479. Figure 4.65 illustrates the economic benefit associated with three different planting dates and two different plant population densities for Pioneer 3237.

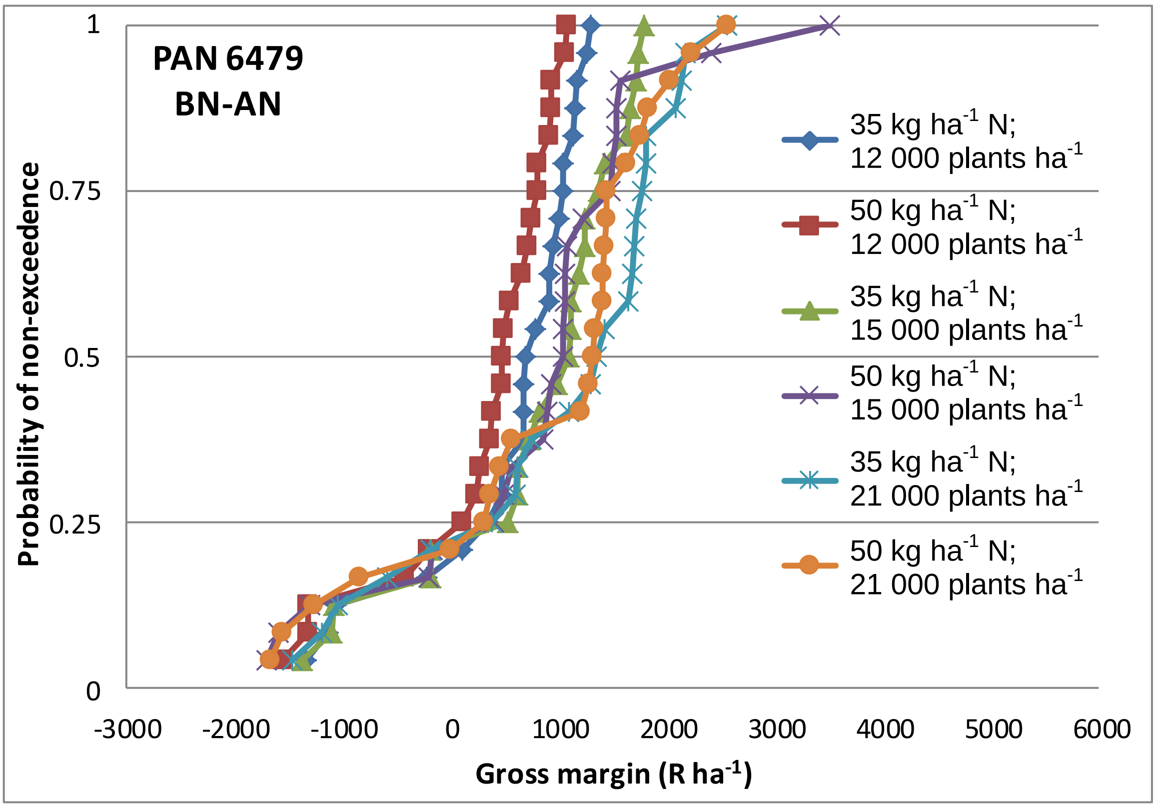


Figure 4.64: Cumulative distribution function of long-term gross margins for PAN 6479 associated with 3 different plant population densities and 2 fertiliser application rates during BN-AN rainfall conditions (planted during 1-15 November and weeding twice).

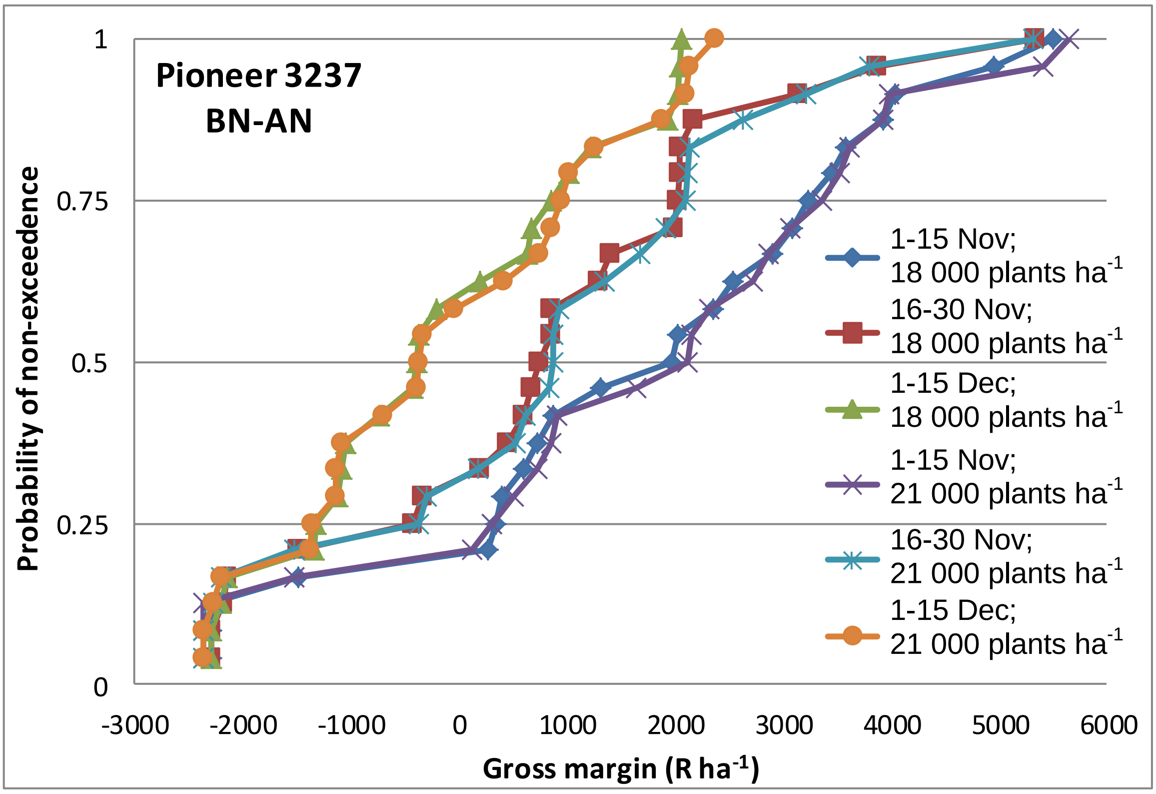


Figure 4.65: Cumulative distribution function of long-term gross margins for Pioneer 3237 associated with 3 different planting dates and 2 plant population densities during BN-AN rainfall conditions (using a fertiliser application rate of 75 kg ha^{-1} N and weeding thrice).

A substantial profit could be obtained by optimising the fertiliser application rate at a timely planting date and optimum weeding frequency for PAN 6479. At the 50% probability of non-exceedence the gross margins for fertiliser application rates of 35 and 50 kg ha^{-1} N at a plant population density of 15 000 plants ha^{-1} was R1 089 ha^{-1} and R1 042 ha^{-1}, respectively (Figure 4.64). The respective field costs were R1 473 ha^{-1} and R1 699 ha^{-1}. An additional profit of R47 ha^{-1} could be gained when opting to use 35 kg ha^{-1} N as opposed to 50 kg ha^{-1} N, while spending R226 ha^{-1} less on field costs. The optimum fertiliser application rate was thus 35 kg ha^{-1} N. The most profitable management practices, given an optimum weeding frequency and fertiliser application rate, involved maximising the plant population density. There was a 75% probability that the gross margin will not exceed R1 035 ha^{-1}, R1 375 ha^{-1} and R1 778 ha^{-1} under a fertiliser application rate of 35 kg ha^{-1} N and plant population densities of 12 000 plants ha^{-1}, 15 000 plants ha^{-1} and 21 000 plants ha^{-1}, respectively. The respective field costs were R1 424 ha^{-1}, R1 473 ha^{-1} and R1 573 ha^{-1}. An additional R743 ha^{-1} could be realised under 21 000 plants ha^{-1} as opposed to 12 000 plants ha^{-1}, while an extra R148 ha^{-1} were spend on field costs.

At the 50% probability of non-exceedence the gross margins for planting Pioneer 3237 during 1-15 November, 16-30 November and 1-15 December under 21 000 plants ha^{-1} were R2 120 ha^{-1}, R884 ha^{-1} and -R366 ha^{-1}, respectively (Figure 4.65). An additional profit of R1 236 ha^{-1} could be made when opting to plant during 1-15 November as opposed to 16-30 November, while making a loss of R366 ha^{-1} when opting to plant during 1-15 December. Thus, the best planting date was 1-15 November. There was a 75% probability that the gross margin will not exceed R3 242 ha^{-1} and R3 367 ha^{-1} when planted during 1-15 November at plant population densities of 18 000 and 21 000 plants ha^{-1}, respectively. The respective field costs were R2 289 ha^{-1} and R2 362 ha^{-1}. Farmers could only gain an additional profit of R125 ha^{-1} when using 21 000 plants ha^{-1} compared to 18 000 plants ha^{-1}, while spending an extra of R73 ha^{-1} on field cost. The optimum plant population density was therefore 18 000 plants ha^{-1}.

4.4.9 Economic analysis of below-normal followed by near-normal (BN-NN) rainfall conditions

The combinations of yield predictors that were subjected to the economic analysis are provided in Appendix A, Table A15 for PAN 6479 and Table A16 for Pioneer 3237. The economic benefits associated with each set of management practices are shown in Appendix B, Table B15 for PAN 6479 and Table B16 for Pioneer 3237.

Statistical analysis of the simulated maize yields presented in section 4.3.9 showed that planting date was the most significant management practice for both cultivars, while plant population density was the least significant. From Table B15 it is evident that the optimum fertiliser application rate was 35 kg ha^{-1} N, while the optimum weeding frequency was 2 times for PAN 6479. For Pioneer 3237, the results presented in Table B16 also indicated that the optimum fertiliser application rate was 35 kg ha^{-1} N, while the optimum weeding frequency was 3 times.

Economic analysis of the different sets of management practices showed that with an optimum fertiliser application rate and weeding frequency a close relationship exists between the planting dates and plant population densities for both cultivars (Appendix B). For PAN 6479, planting dates of 1-15 November, 16-30 November and 1-15 December contributed more to maize yields than 16-30 December and 1-15 January, while the plant population densities that maximised yields were 12 000 and 15 000 plants ha^{-1}. For Pioneer 3237, the planting dates that contributed more to maize yields were 1-15 November and 16-30 November, while plant population densities of 12 000, 15 000 and 18 000 plants ha^{-1} provided higher yields than 9 000 and 21 000 plants ha^{-1}. The CDFs in Figure 4.66 illustrate the economic benefit associated with three different planting dates and two plant population densities during BN-NN rainfall conditions for PAN 6479. Figure 4.67 illustrates the CDFs of the economic benefit associated with two different planting dates and three plant population densities for Pioneer 3237.

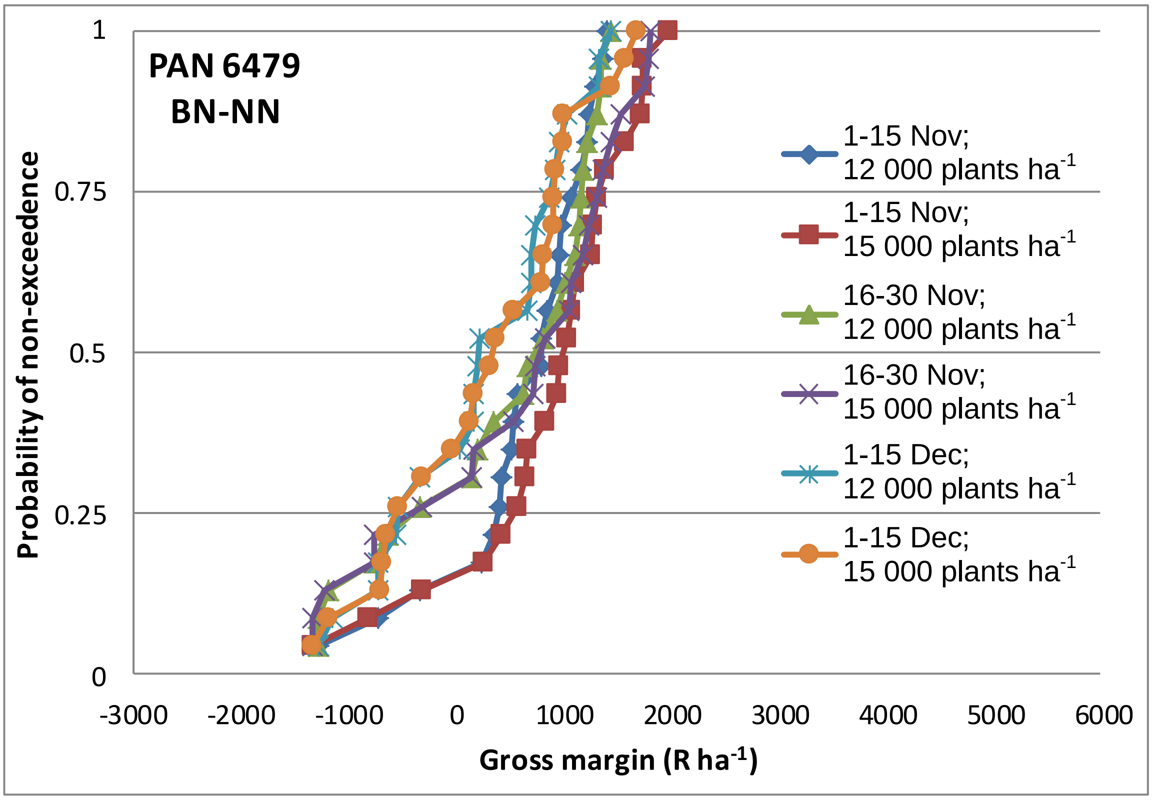


Figure 4.66: Cumulative distribution function of long-term gross margins for PAN 6479 associated with 3 different planting dates and 2 plant population densities during BN-NN rainfall conditions (using a fertiliser application rate of 35 kg ha^{-1} N and weeding twice).

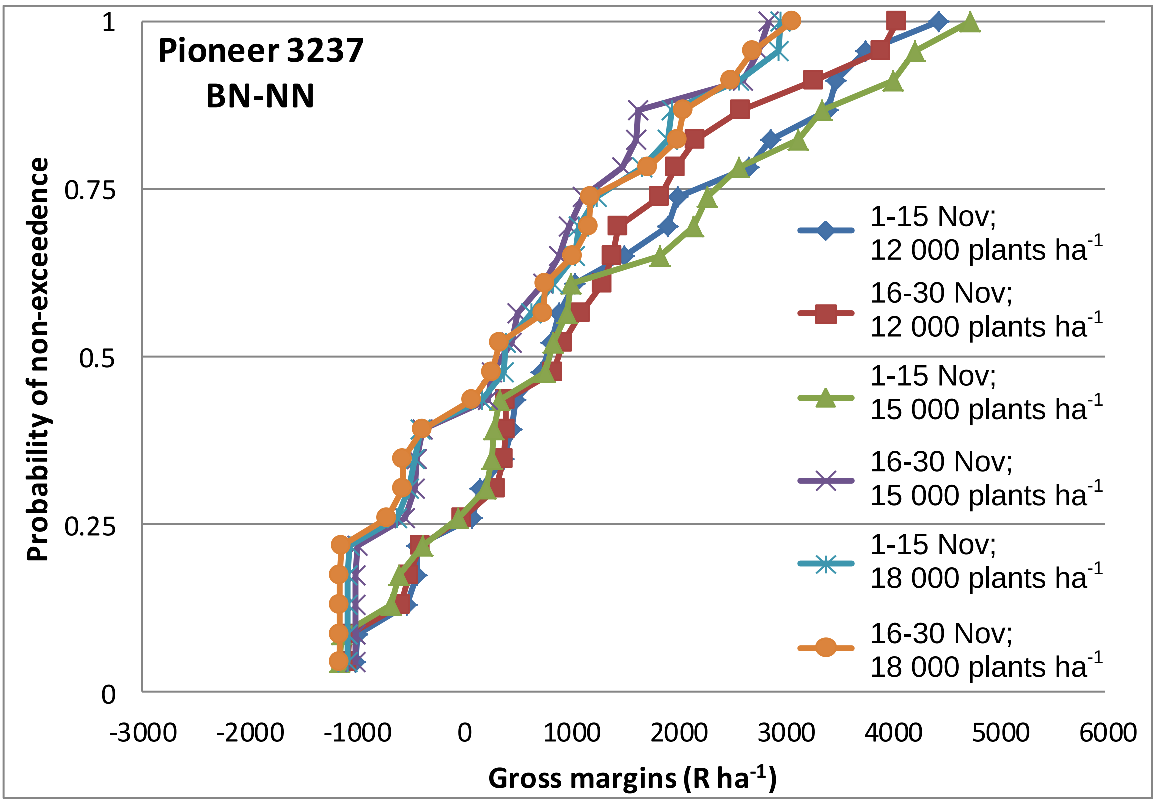


Figure 4.67: Cumulative distribution function of long-term gross margins for Pioneer 3237 associated with 2 different planting dates and 3 plant population densities during BN-NN rainfall conditions (using a fertiliser application rate of 35 kg ha^{-1} N and weeding thrice).

For PAN 6479 the most profitable management practices, given an optimum fertiliser application rate and weeding frequency, involved planting earlier. At the 50% probability of non-exceedence the gross margins for planting during 1-15 November, 16-30 November and 1-15 December at a plant population density of 15 000 plants ha^{-1} were R1 038 ha^{-1}, R828 ha^{-1} and R368 ha^{-1}, respectively (Figure 4.66). The difference in profit between planting during 1-15 November and 1-15 December was R670 ha^{-1}. An additional profit of R110 ha^{-1} could be obtained when opting to plant during 1-15 November as opposed to 16-30 November. The best planting date was therefore 1-15 November. There was a 75% probability that the gross margin would not exceed R1 077 ha^{-1} and R1 310 ha^{-1} when planted during 1-15 November at plant population densities of 12 000 and 15 000 plants ha^{-1}, respectively. The respective field costs were R1 424 ha^{-1} and R1 473 ha^{-1}. Thus, farmers could obtain an additional profit of R143 ha^{-1} when opting to plant 15 000 plants ha^{-1} as opposed to 12 000 plants ha^{-1}, after spending an additional R49 ha^{-1} on field costs. Thus, the optimum plant population density was 15 000 plant ha^{-1}.

Profits could be maximised by planting Pioneer 3237 earlier under an optimum weeding frequency and fertiliser application rate (Figure 4.67). At the 50% probability of non-exceedence the gross margins for sowing 15 000 plants ha^{-1} during 1-15 November and 16-30 November were R494 ha^{-1} and R58 ha^{-1}, respectively. Thus, farmers could obtain an additional profit of R436 ha^{-1} when opting to plant during 1-15 November as opposed to 16-30 November. The gross margins for planting 12 000 plants ha^{-1} during 1-15 November and 16-30 November were R519 ha^{-1} and R87 ha^{-1}, respectively. There was a 75% probability that the gross margin will not exceed R1 242 ha^{-1}, R1 223 ha^{-1} and R479 ha^{-1} when using plant population densities of 12 000, 15 000 and 18 000 plants ha^{-1}, respectively. The respective field costs were R1 542 ha^{-1}, R1 615 ha^{-1} and R1 689 ha^{-1}. Thus, farmers could obtain an additional profit of R763 ha^{-1} when opting to sow 12 000 plants ha^{-1} as opposed to 18 000 plants ha^{-1}, after spending R147 ha^{-1} less on field costs. On the other hand, an additional profit of R19 ha^{-1} could be realised when opting to sow 12 000 plants ha^{-1} as opposed to 15 000 plants ha^{-1}, after spending R74 ha^{-1} less on field costs. The optimum plant population density for Pioneer 3237 was therefore 12 000 plants ha^{-1}.

4.4.10 Economic analysis of below-normal followed by below-normal (BN-BN) rainfall conditions

The combinations of yield predictors that were subjected to economic analysis are provided in Appendix A, Table A17 for PAN 6479 and Table A18 for Pioneer 3237. The economic benefits associated with each set of management practices are shown in Appendix B, Table B17 for PAN 6479 and B18 for Pioneer 3237.

The choice of planting date was the most significant management practice for both cultivars (section 4.3.10), while plant population density was the least. From the data presented in Tables B17 and B18 it is evident that the optimum fertiliser application rate was 35 kg ha^{-1} N, while the optimum weeding frequency was 2 times for both cultivars.

Economic analysis of the different sets of management practices showed that with an optimum fertiliser application rate and weeding frequency a close relationship existed between planting date and plant population density for both cultivars (Appendix B). For PAN 6479, planting dates of 1-15 November, 16-30 November and 1-15 December contributed more to maize yields than 16-30 December and 1-15 January, while plant population densities of 9 000 and 12 000 plants ha^{-1} produced higher yields. For Pioneer 3237 the planting dates that contributed more to maize yields were 1-15 November and 16-30 November. Plant population densities of 9 000, 12 000 and 15 000 plants ha^{-1} also provided higher yields than 18 000 and 21 000 plants ha^{-1}. The CDFs in Figure 4.68 illustrate the economic benefit associated with three different planting dates and two different plant population densities during BN-BN rainfall conditions for PAN 6479. Figure 4.69 also illustrate the CDFs of the economic benefit associated with two different planting dates and three plant population densities during BN-BN rainfall conditions for Pioneer 3237.

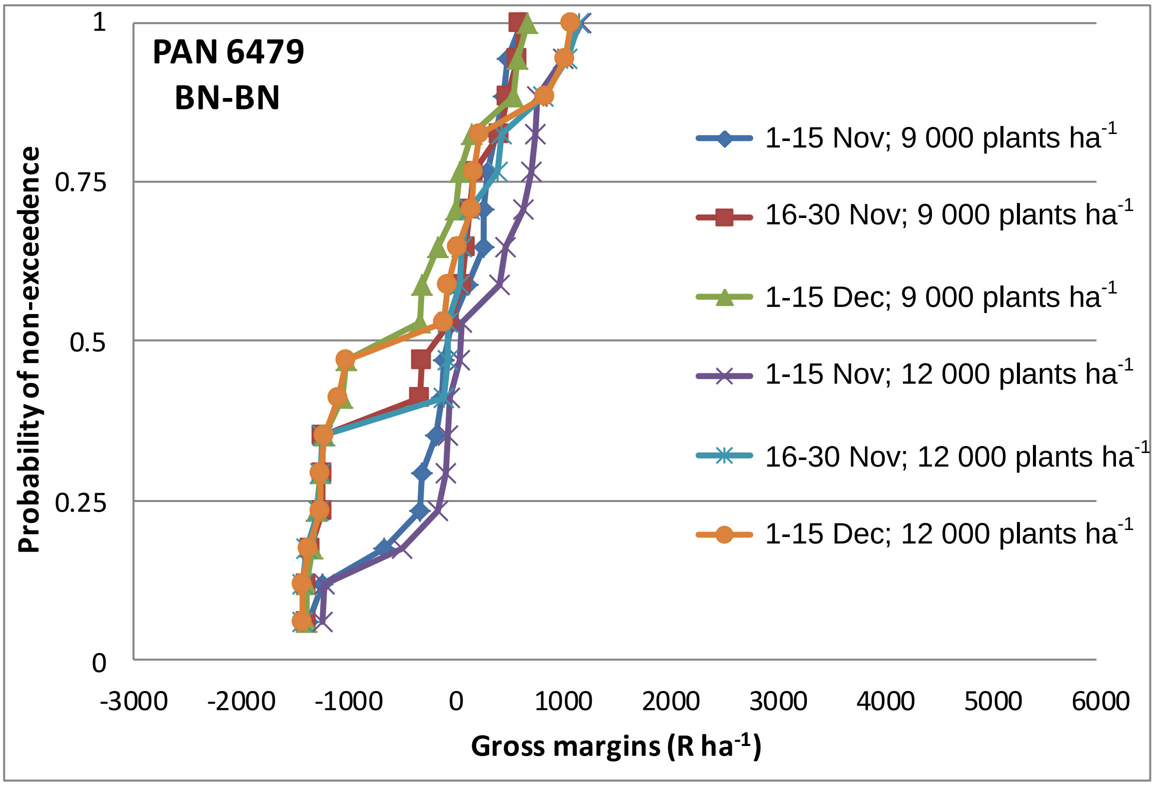


Figure 4.68: Cumulative distribution function of long-term gross margins for PAN 6479 associated with 3 different planting dates and 2 plant population densities during BN-BN rainfall conditions (using a fertiliser application rate of 35 kg ha^{-1} N and weeding twice).

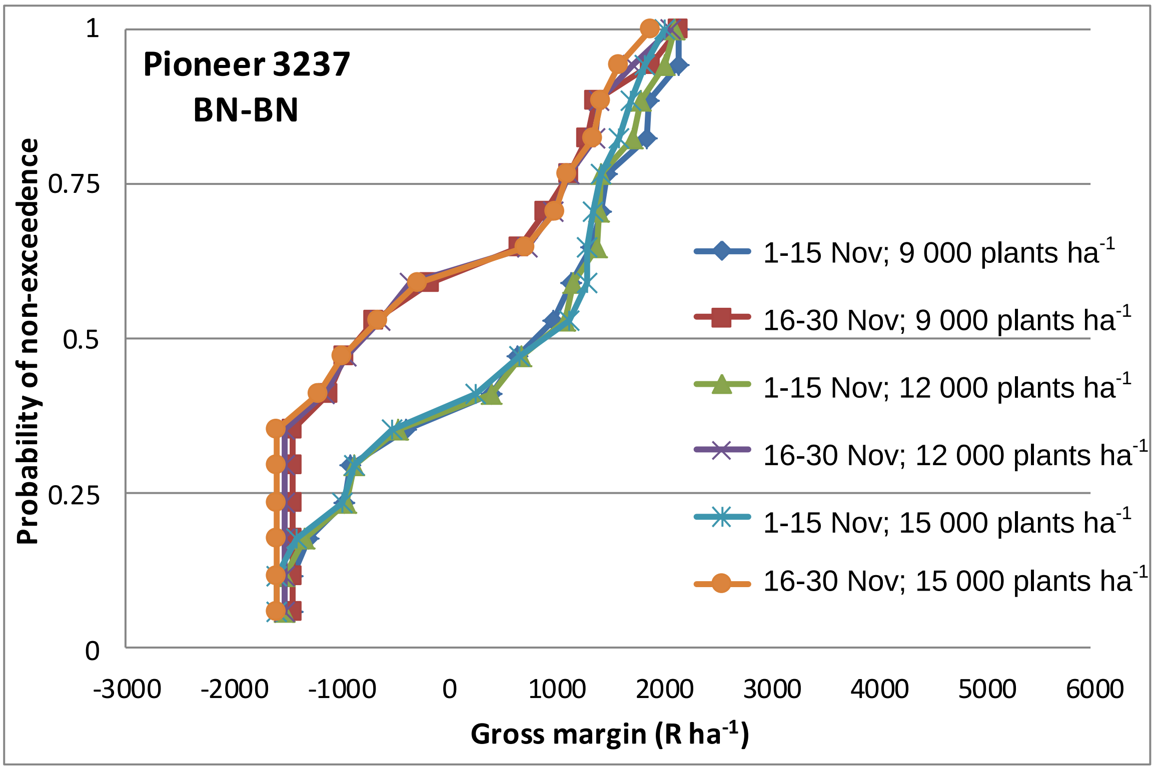


Figure 4.69: Cumulative distribution function of long-term gross margins for Pioneer 3237 associated with 2 different planting dates and 3 different plant population densities during BN-BN rainfall conditions (using a fertiliser application rate of 35 kg ha^{-1} N and weeding twice).

At the 50% probability of non-exceedence the gross margins for planting PAN 6479 during 1-15 November, 16-30 November and 1-15 December at 12 000 plants ha^{-1} were R66 ha^{-1}, -R64 ha^{-1} and -R105 ha^{-1}, respectively (Figure 4.68). The difference in profit between 1-15 November and 1-15 December was R171 ha^{-1}, while the difference in profit between 1-15 November and 16-30 November was R130 ha^{-1}. The best planting date was therefore 1-15 November. A substantial profit could be attained by optimising the plant population density at an optimum planting date, optimum fertiliser application rate and weeding frequency. There was a 75% probability that the gross margin would not exceed R306 ha^{-1} and R709 ha^{-1} when planted during 1-15 November at plant population densities of 9 000 and 12 000 plants ha^{-1}, respectively. The respective field costs were R1 374 ha^{-1} and R1 424 ha^{-1}. An additional R406 ha^{-1} could be obtained when using 12 000 plants ha^{-1} instead of 9 000 plants ha^{-1}, after investing an additional R50 ha^{-1} in field costs.

For Pioneer 3237 (Figure 4.69) the profit could be maximised by planting earlier at an optimum weeding frequency and fertiliser application rate. At the 50% probability of non-exceedence the gross margins for planting during 1-15 November and 16-30 November under a plant population density of 15 000 plants ha^{-1} were R1 121 ha^{-1} and -R644 ha^{-1}, respectively. The difference in profit between 1-15 November and 16-30 November was R1 765 ha^{-1}. Since the gross margin was negative, it meant that farmers would make a loss when choosing to plant after 1-15 November. There was a 75% probability that the gross margin would not exceed R1 482 ha^{-1}, R1 421 ha^{-1} and R1 435 ha^{-1} when using plant population densities of 9 000, 12 000 and 15 000 plants ha^{-1} planted during 1-15 November, respectively. The respective field costs were R1 445 ha^{-1}, R1 518 ha^{-1} and R1 591 ha^{-1}. Farmers could obtain an additional profit of R61 ha^{-1} when using 9 000 plants ha^{-1} instead of 12 000 plants ha^{-1}, after spending R73 ha^{-1} less on field cost. Thus, the optimum plant population density was 9 000 plants ha^{-1}.

4.5 Recommended practices for rainfed maize production under various seasonal rainfall conditions

4.5.1 Background

Management practices could be adjusted to achieve higher yields. Through the use of seasonal forecasts the inputs can be increased during wet years and reduced during years when the chances for lower yields are high (Plant, 2000). Combining seasonal rainfall forecasts and model simulations to evaluate management practices could maximise the profitability of farm operations by reducing the climatic risk considerably (Hammer *et al*., 2001). Dorward *et al.* (1997) used advisory practices for farm management to assess the performance and intervention in agriculture by researchers, planners and service providers. In this research project the advisories were based on the seasonal rainfall and took the form of flow charts. The flow charts presented consist of three main sections, namely the seasonal rainfall conditions; management practices and economic analysis.

The seasonal rainfall section provides information pertaining to the OND rainfall scenario followed by the JFM rainfall scenario. Amongst others, the South African Weather Service (SAWS) issues a “Seasonal Forecast Overview for South Africa” on a monthly basis. These forecasts can be consulted at the beginning of the crop growth season in order to judge the rainfall conditions of the current and upcoming season (3-month period). Users will then have to locate the relevant flow chart. The management practices section include a sequence of significant yield predictors from the highest to the lowest ranked together with their respective best, second best and worst options for the given seasonal rainfall scenario. The last section provides an economic analysis and contains details about the field costs and economic benefits (gross margins) of the best and worst management practices at the 25, 50 and 75% probability levels.

Readers are again advised that the advisories presented in this section cannot be used in practice to advice farmers as the model’s validation was not satisfactory.

4.5.2 Recommended practices during above-normal followed by above-normal (AN-AN) rainfall conditions

The recommended practices during AN-AN rainfall conditions for PAN 6479 and Pioneer 3237 were discussed in section 4.4.2. These practices are now summarised by the flow charts in Figure 4.70 and Figure 4.71. As indicated in Figure 4.70 the best set of management practices for PAN 6479 during AN-AN rainfall conditions involved planting during 16-30 November, a fertiliser application rate of 50 kg ha^{-1} N, weeding twice during the growth season and using a plant population density of 21 000 plants ha^{-1}. The economic analysis revealed a 50% probability of obtaining R1 972 ha^{-1} under the best management practices, while the field costs amount to R1 798 ha^{-1}. Since planting date was the most important yield contributor, the second best set of management practices for PAN 6479 involved planting during 1-15 November using a 50 kg ha^{-1} N, weeding twice and 21 000 plants ha^{-1}. The economic analysis for these sets of management practices are provided in Table B1 (Appendix B). The worst management strategy involved planting during 1-15 January, applying 100 kg ha^{-1} N and not weeding at all whilst using 9 000 plants ha^{-1}. Under these conditions farmers would spend R2 301 ha^{-1} and risk making a loss of R2 019 ha^{-1} at the same probability level.

During AN-AN rainfall conditions, the best set of management practices for Pioneer 3237 involved planting during 1-15 November, applying 75 kg ha^{-1} N of fertiliser, weeding twice and using a plant population density of 21 000 plants ha^{-1} (Figure 4.71). As a result farmers would spend R2 338 ha^{-1} on field costs, while obtaining a yield of 4 232 kg ha^{-1} and making a profit of R3 253 ha^{-1} at the 50% probability level. Planting date was the most important yield contributor followed by fertiliser application rate, weeding frequency and plant population density. The best set of management practices in combination of 16-30 November, 75 kg ha^{-1} N, weeding twice and a 21 000 plants ha^{-1}. The worst set of management practices involved planting during 1-15 January, applying no fertiliser, no weeding and plant 9 000 plants ha^{-1}. Farmers would then obtain a meagre yield of 22 kg ha^{-1} which resulted in losing R846 ha^{-1} at the same probability level.

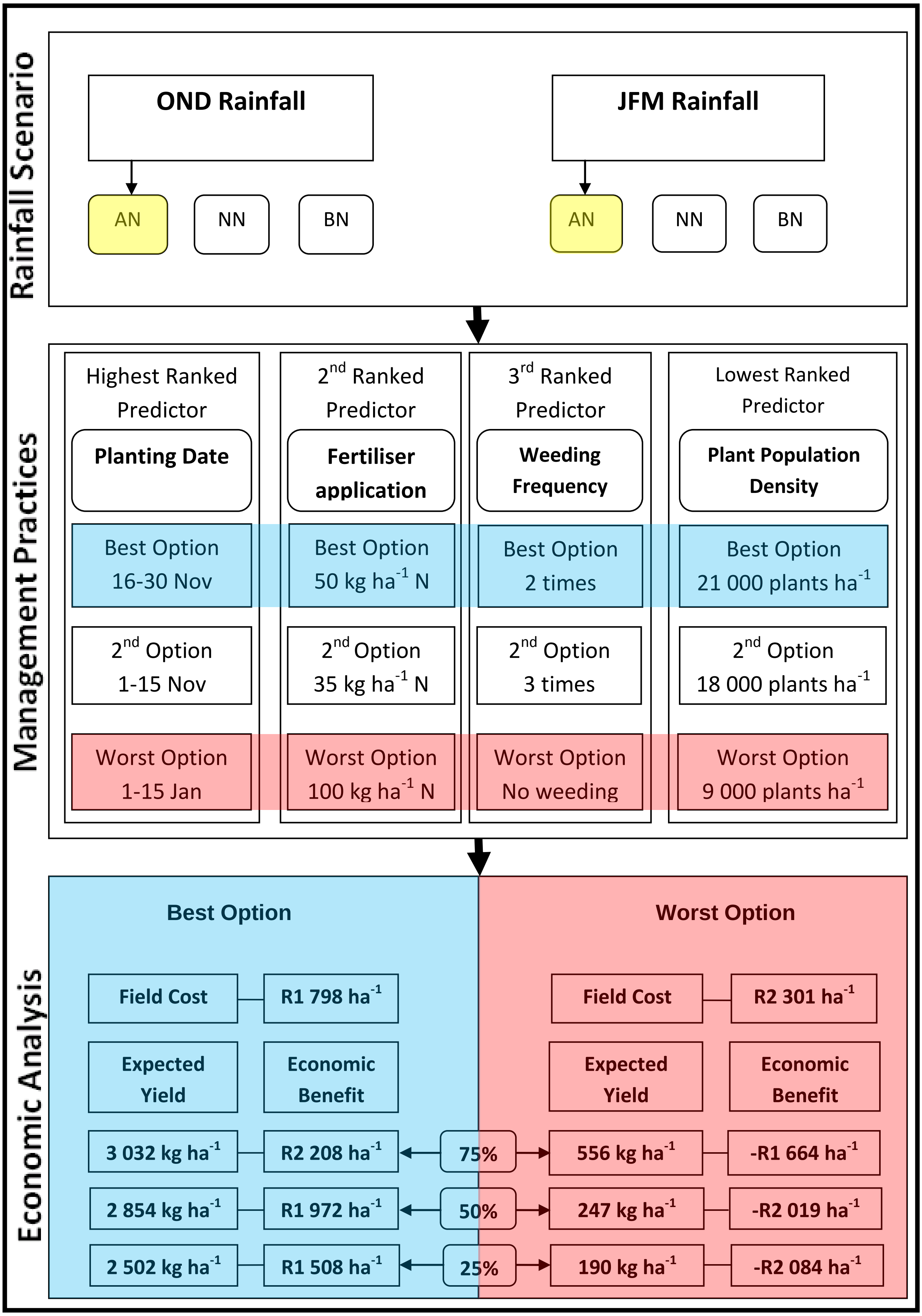


Figure 4.70: Flow chart of recommended practices for PAN 6479 during AN-AN rainfall conditions.

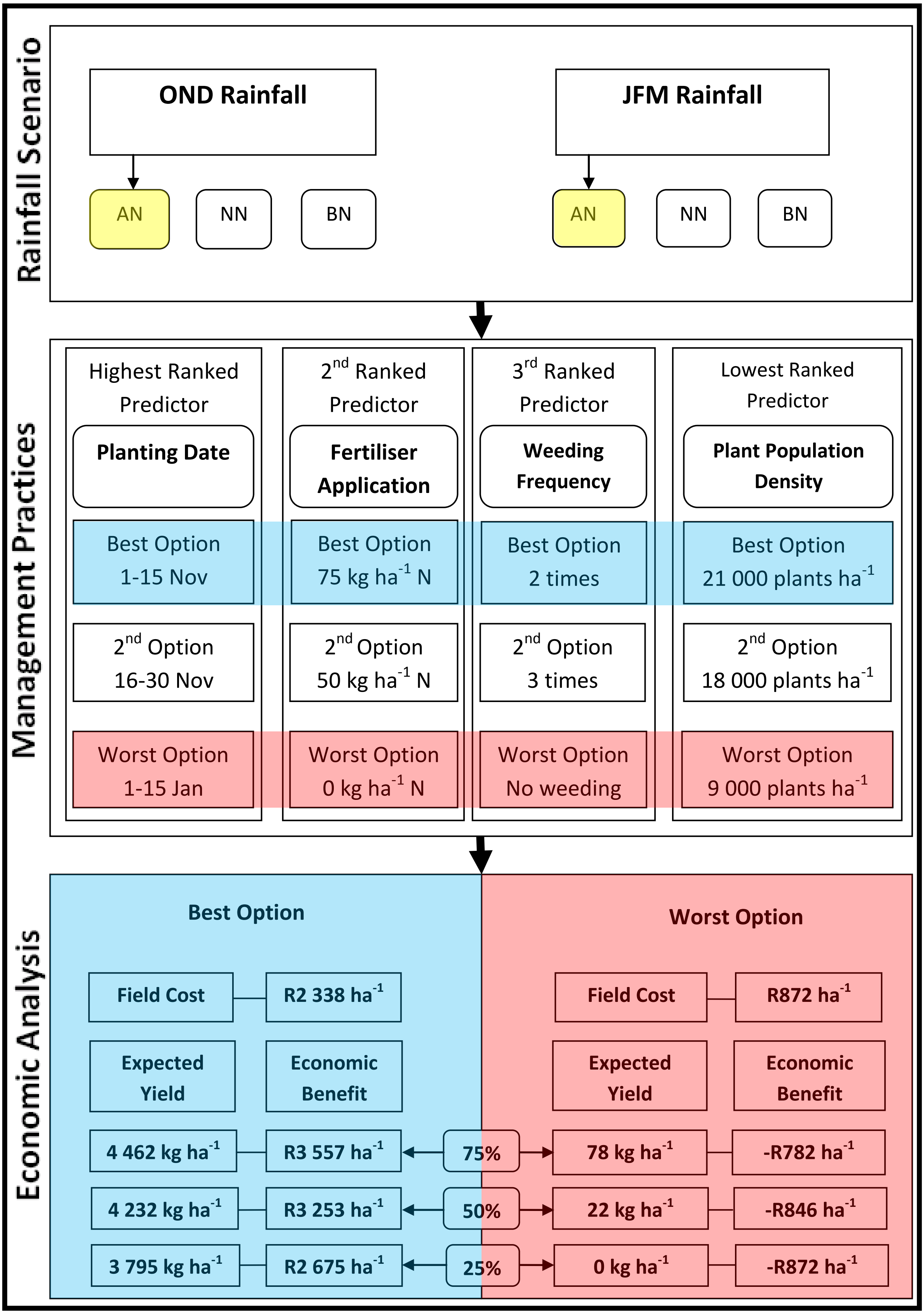


Figure 4.71: Flow chart of recommended practices for Pioneer 3237 during AN-AN rainfall conditions.

4.5.3 Recommended practices during above-normal followed by near-normal (AN-NN) rainfall conditions

The dominant yield predictors identified in section 4.4.3 were used in the recommended management practices for PAN 6479 and Pioneer 3237 during AN-NN rainfall conditions (Figure 4.72 and Figure 4.73). The best set of management practices for PAN 6479 during these rainfall conditions involved weeding twice, planting during 16-30 November, applying 35 kg ha^{-1} N and using a plant population density of 21 000 plants ha^{-1} (Figure 4.72). Farmers could obtain a yield of 2 323 kg ha^{-1} and making a profit of R1 496 ha^{-1} at the 75% probability level, after spending R 1 572 ha^{-1} on field costs. Weeding frequency was the most important yield contributor followed by planting date, fertiliser application rate and plant population density. When forced to use an alternative weeding frequency, the next best set of management practices involved weeding once, using the optimum planting date (16-30 November) with an optimum fertiliser application rate (35 kg ha^{-1} N) and optimum plant population density (21 000 plants ha^{-1}). The worst set of management practices involved not weeding at all, planting during 1-15 January, applying no fertiliser and using 9 000 plants ha^{-1}. Farmers would then spend R801 ha^{-1} on field cost and run the risk of making a loss of R635 ha^{-1} at the same probability level.

The best set of management practices for Pioneer 3237 involved planting during 1-15 November, applying 75 kg ha^{-1} N of fertiliser, weeding three times and using 12 000 plants ha^{-1} (Figure 4.73). The economic analysis revealed a 50% probability of farmers making a profit of R2 726 ha^{-1} under the best management decision. Since planting date was the most important yield contributor, the next best set of management practices in combination with an alternative date involved planting during 16-30 November and using the optimum values for fertiliser application rate, weeding frequency and plant population density. The economic analysis for this set of management practices is provided in Table B4 (Appendix B). The worst management decision was to plant during 1-15 January, with no weeding control, applying no fertiliser and planting 21 000 plants ha^{-1}. Under these conditions farmers would run the risk of making a loss of R1 164 ha^{-1} due to crop failure.

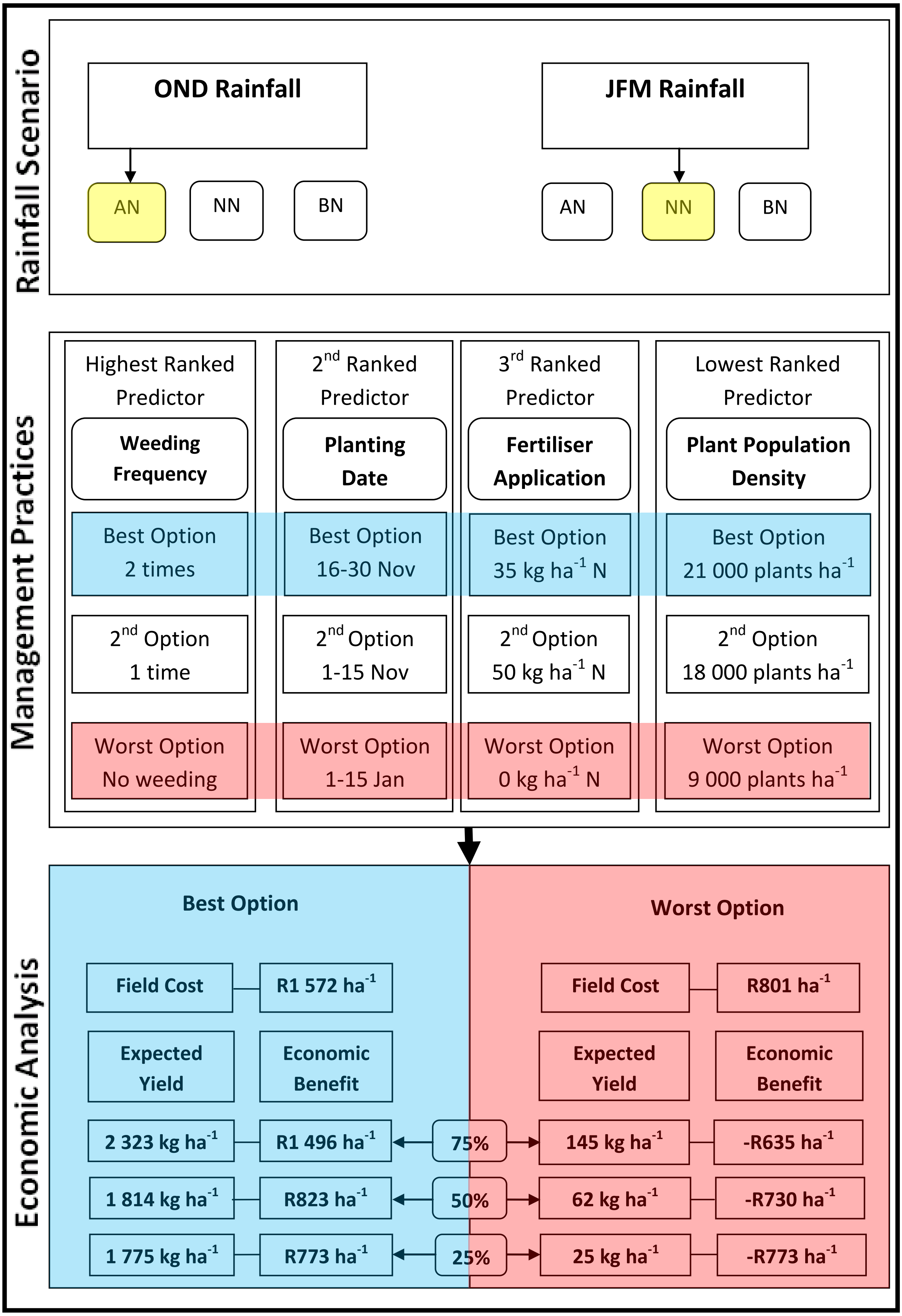


Figure 4.72: Flow chart of recommended practices for PAN 6479 during AN-NN rainfall conditions.

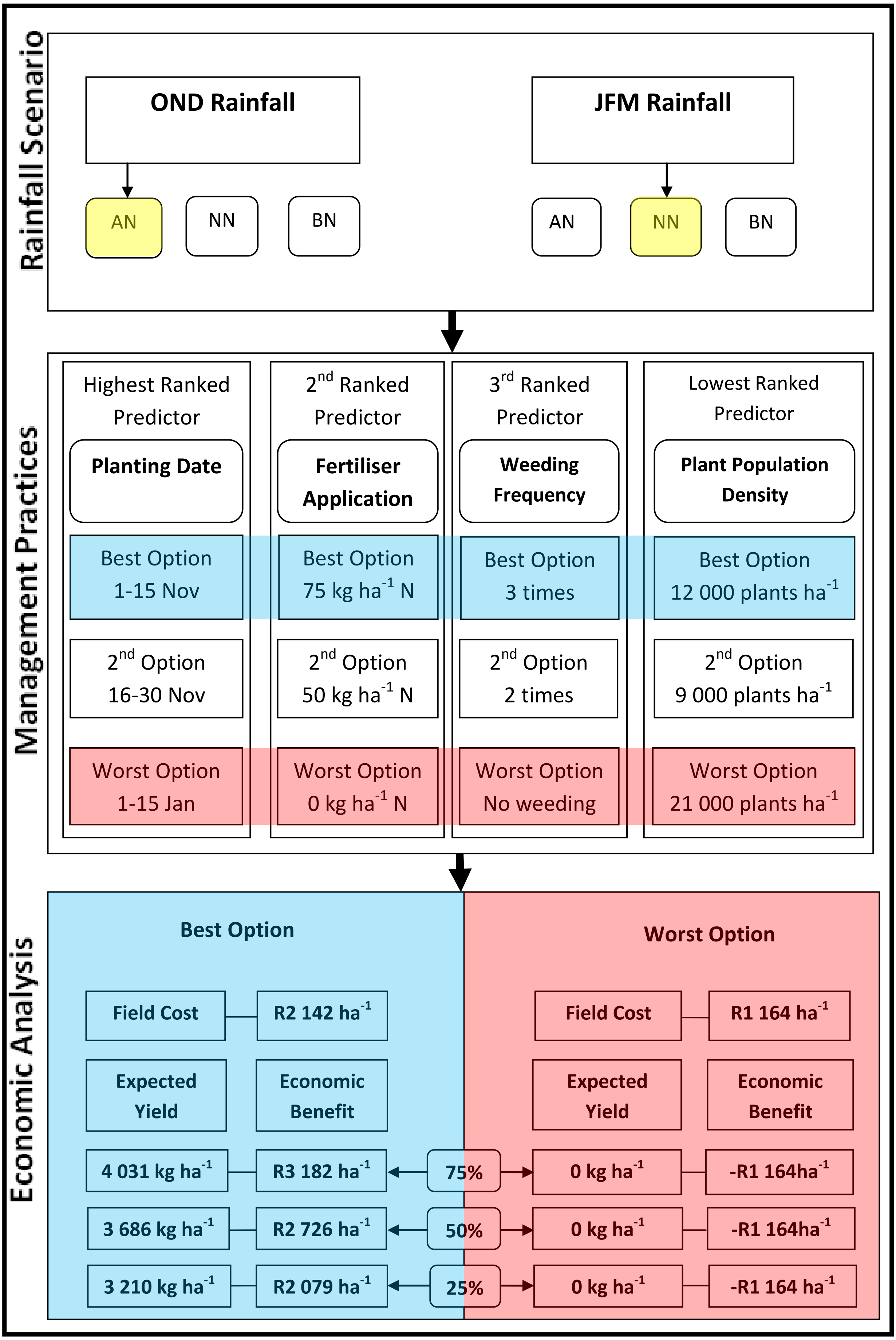


Figure 4.73: Flow chart of recommended practices for Pioneer 3237 during AN-NN rainfall conditions.

4.5.4 Recommended practices during above-normal followed by below-normal (AN-BN) rainfall conditions

The recommended management practices during AN-BN rainfall conditions for PAN 6479 and Pioneer 3237 were discussed in section 4.4.4. The best set of management practices for PAN 6479 during these seasonal rainfall conditions involved weeding twice, planting during 16-30 November, applying 35 kg ha^{-1} N of fertiliser and using a plant population density of 15 000 plants ha^{-1} (Figure 4.74). Farmers would spend R1 473 ha^{-1} on field costs, while obtaining a yield of 2 031 kg ha^{-1} and a profit of R1 253 ha^{-1} at the 75% probability level. Since weeding frequency was the most important yield contributor, the next best set of management practices for PAN 6479 in combination with an alternative weeding frequency involved weeding once, using the optimum planting date (16-30 November), optimum fertiliser application rate (35 kg ha^{-1} N) and optimum plant population density (15 000 plants ha^{-1}). The worst set of management practices involved not weeding at all during the growth season, planting during 1-15 January, applying 100 kg ha^{-1} N of fertiliser and using 21 000 plants ha^{-1}. Under the worst management practices farmers would spend R2 499 kg ha^{-1} and risk making a loss of R2 286 ha^{-1} at the same probability level.

During AN-BN rainfall conditions, the best set of management practices for Pioneer 3237 involved planting during 1-15 November, weeding 3 times, applying 50 kg ha^{-1} N and planting 9 000 plants ha^{-1} (Figure 4.75). The economic analysis revealed a 50% probability of farmers obtaining R1 412 ha^{-1}, after spending R1 694 ha^{-1} on field costs. Planting date was the highest contributing yield predictor followed by weeding frequency, fertiliser application rate and plant population density. When forced to use an alternative planting date, the next best set of management practices involved planting during 16-30 November and using optimum values of fertiliser application rate, weeding frequency and plant population density. The worst set of management practices involved planting during 1-15 January, no weeding control, applying 100 kg ha^{-1} N and planting 21 000 plants ha^{-1}. As a result farmers would spend R2 664 ha^{-1} on field costs and risk losing everything due to crop failure at all three probability levels.

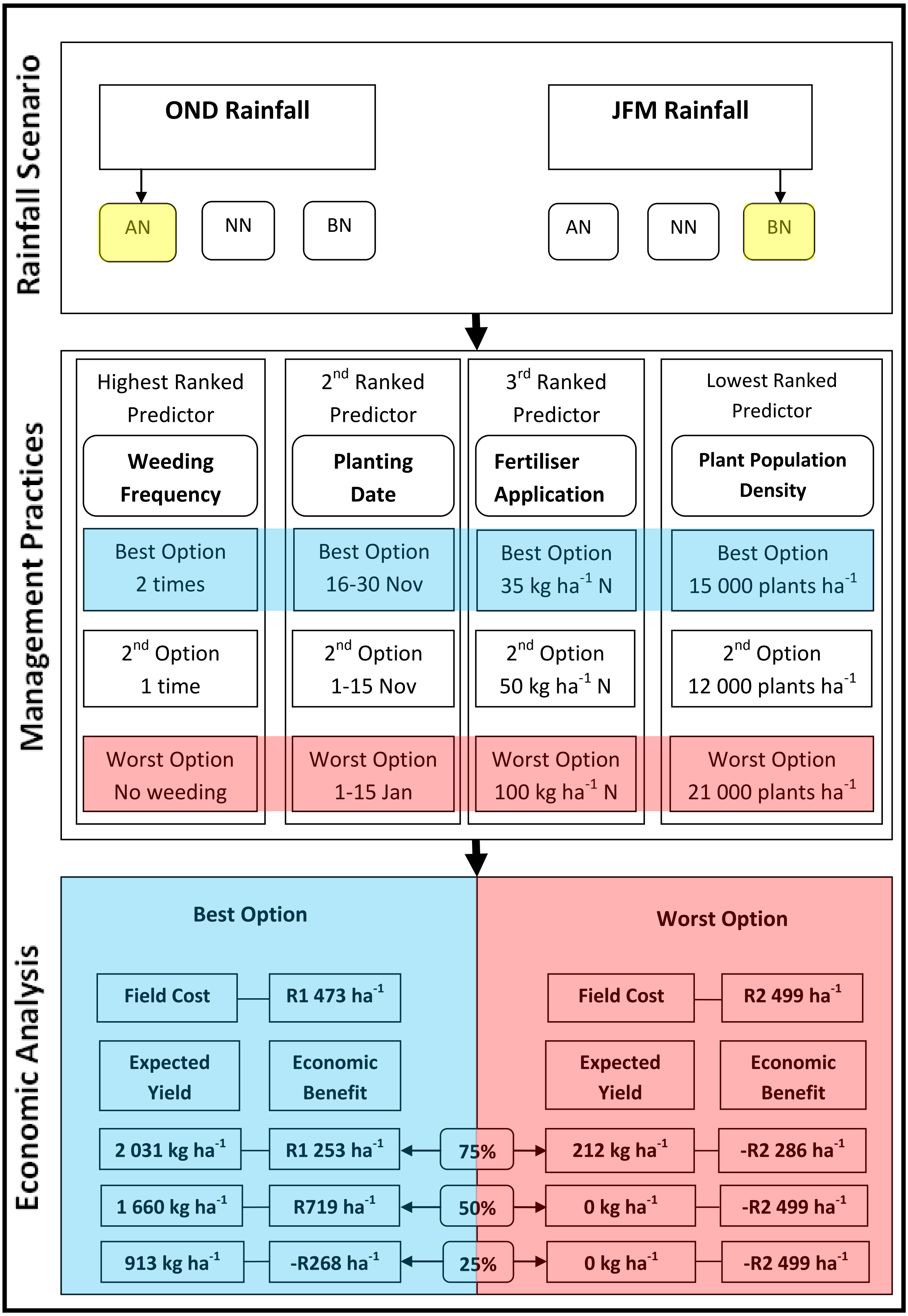


Figure 4.74: Flow chart of recommended practices for PAN 6479 during AN-BN rainfall conditions.

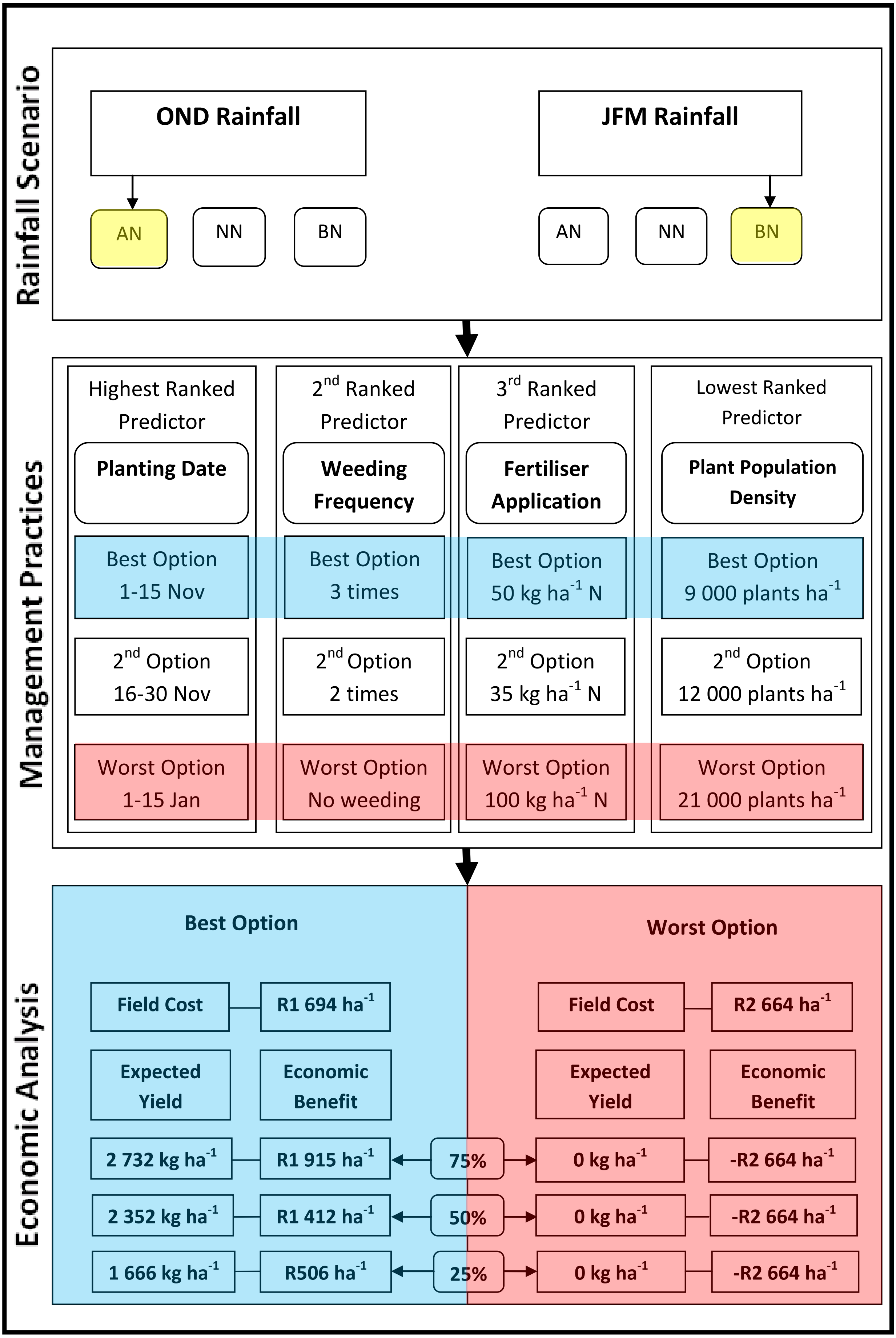


Figure 4.75: Flow chart of recommended practices for Pioneer 3237 during AN-BN rainfall conditions.

4.5.5 Recommended practices during near-normal followed by above-normal (NN-AN) rainfall conditions

The results presented in section 4.4.5 showed that the best set of management practices for PAN 6479 during NN-AN rainfall conditions involved planting during 16-30 November, applying 50 kg ha^{-1} N, weeding twice using a plant population density 21 000 plants ha^{-1} (Figure 4.76). The worst management practice was to plant during 1-15 January, applying 100 kg ha^{-1} N, and no weeding control with 9 000 plants ha^{-1}. The economic analysis showed a 75% probability of farmers obtaining a profit of R2 298 ha^{-1} and spending R1 798 ha^{-1} on field costs under the best management practices, while making a loss of R1 763 ha^{-1} while spending R2 301 ha^{-1} on field costs under the worst management practices. Although planting date was the highest yield contributor, the next best set of management practices for PAN 6479 in combination with an alternative date involved planting during 1-15 November. The economic analysis for this set of management practices is available in Table B7 (Appendix B).

As indicated in Figure 4.77, the best set of management practices for Pioneer 3237 during these rainfall conditions involved planting during 1-15 November, applying 75 kg ha^{-1} N, weeding 3 times and planting 18 000 plants ha^{-1}. Farmers would obtain a yield of 3 824 kg ha^{-1} and make a profit of R2 763 ha^{-1} at the 50% probability level. Due to planting date being the highest ranked predictor, the next best set of management practices involved planting during 16-30 November with an optimum fertiliser application rate (75 kg ha^{-1} N), optimum weeding frequency (3 times) and optimum plant population density (18 000 plants ha^{-1}). The worst set of management practices involved planting during 1-15 January, applying no fertiliser and no weeding control and using 9 000 plants ha^{-1}. Farmers would spend R872 ha^{-1} on field costs, while losing everything due to crop failure at the 50% probability level.

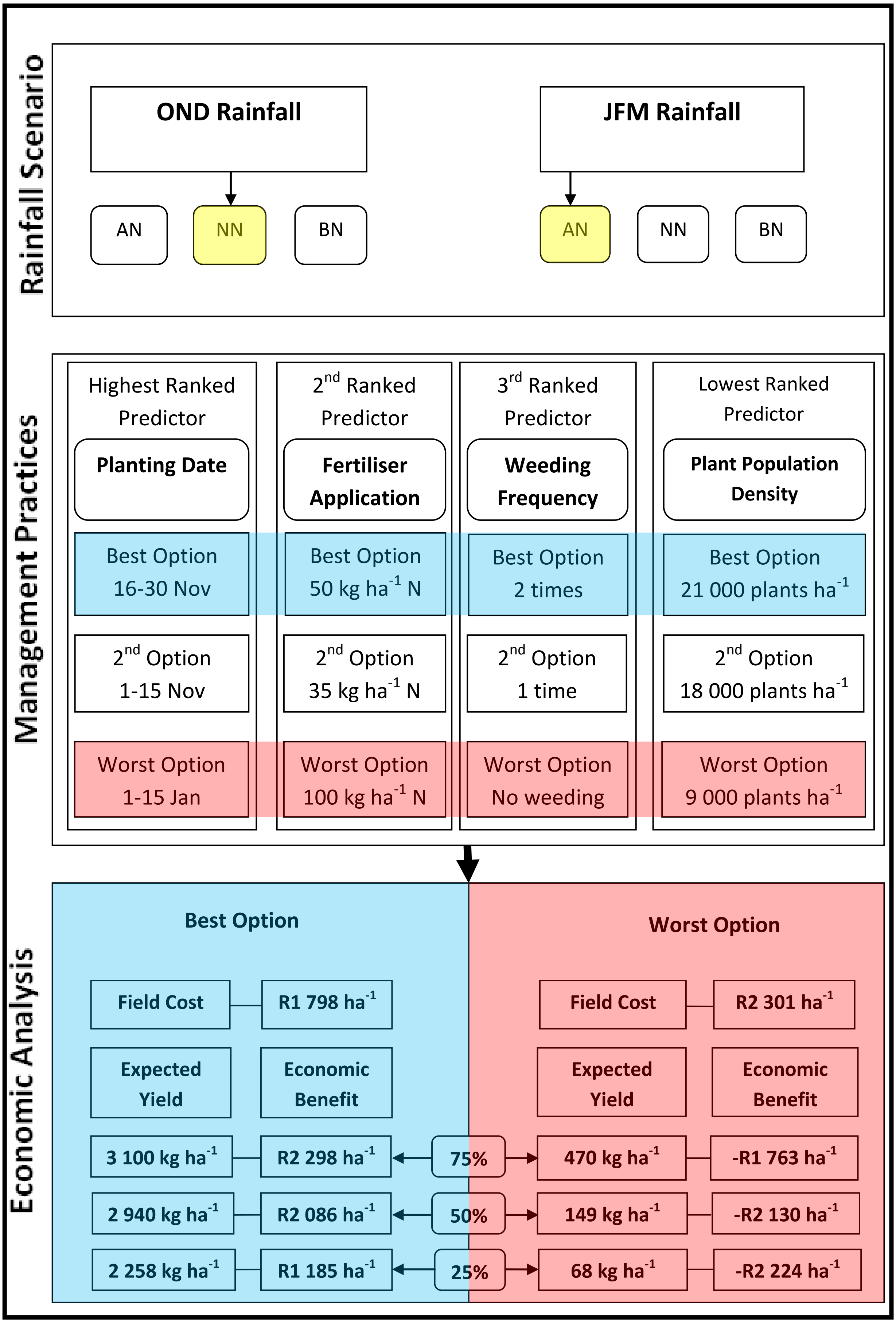


Figure 4.76: Flow chart of recommended practices for PAN 6479 during NN-AN rainfall conditions.

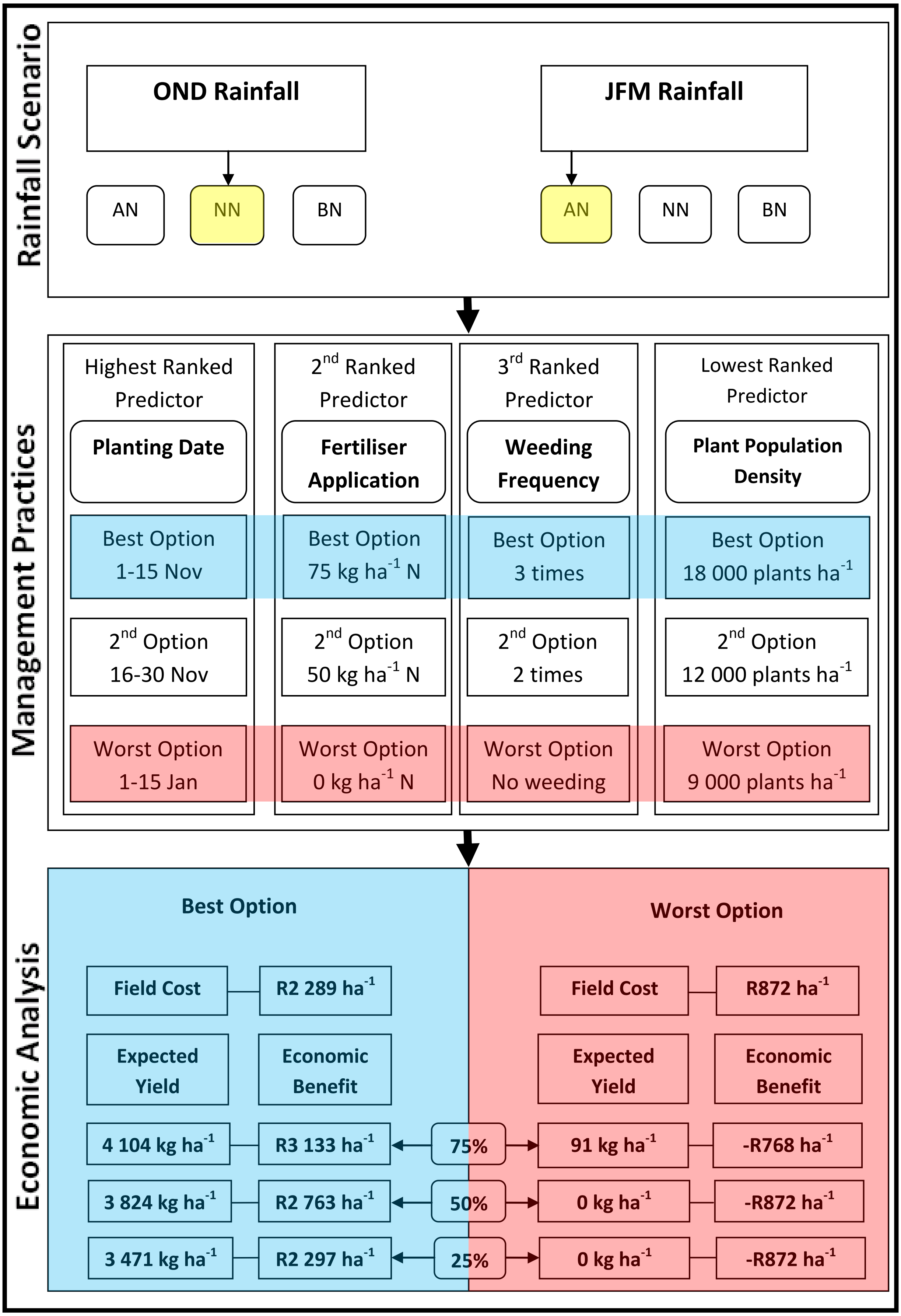


Figure 4.77: Flow chart of recommended practices for Pioneer 3237 during NN-AN rainfall conditions.

4.5.6 Recommended practices during near-normal followed by near-normal (NN-NN) rainfall conditions

The optimal yield predictors identified in section 4.4.6 were used as recommended management practices for PAN 6479 and Pioneer 3237 during NN-NN rainfall conditions. These practices are now summarised by the flow charts in Figure 4.78 and Figure 4.79 for PAN 6479 and Pioneer 3237, respectively. During these rainfall conditions the best set of management practices for PAN 6479 involved weeding twice, applying 35 kg ha^{-1} N, planting during 1-15 November using a plant population density of 15 000 plants ha^{-1}. As a result farmers would spend R 1 473 ha^{-1} on field costs, while obtaining a yield of 2 159 kg ha^{-1} and making a profit of R1 378 ha^{-1} at the 75% probability level. The next best set of management practices involved weeding once with the optimum values for fertiliser application rate, planting date and plant population density. The worst management practice involved no weeding control, applying 100 kg ha^{-1} N, planting during 1-15 January at a plant population density of 21 000 plants ha^{-1}. Farmers would spend R2 499 ha^{-1} on field costs due to the high plant population density and fertiliser application rate and risk making a loss of R1 698 ha^{-1} at the same probability level.

During NN-NN rainfall conditions the best set of management practices for Pioneer 3237 involved planting during 1-15 November, weeding twice, applying 75 kg ha^{-1} N and using a plant population density of 21 000 plants ha^{-1} (Figure 4.79). The worst set of management practices involved planting during 1-15 January, without weeding and applying fertiliser and using 9 000 plants ha^{-1}. The economic analysis revealed that at a 75% probability, farmers have the chance of making a profit of R2 708 ha^{-1} under the best management practices, while making a loss of R708 ha^{-1}. Farmers would then obtain a profit of R2 708 ha^{-1} and spend R2 338 ha^{-1} on field costs. When using the worst set of management practices, farmers would make a loss of R872 ha^{-1} at the 50% probability level. Planting date was the most important yield contributor, which meant that the next best set of management practices under an alternative date involved planting during 16-30 November.

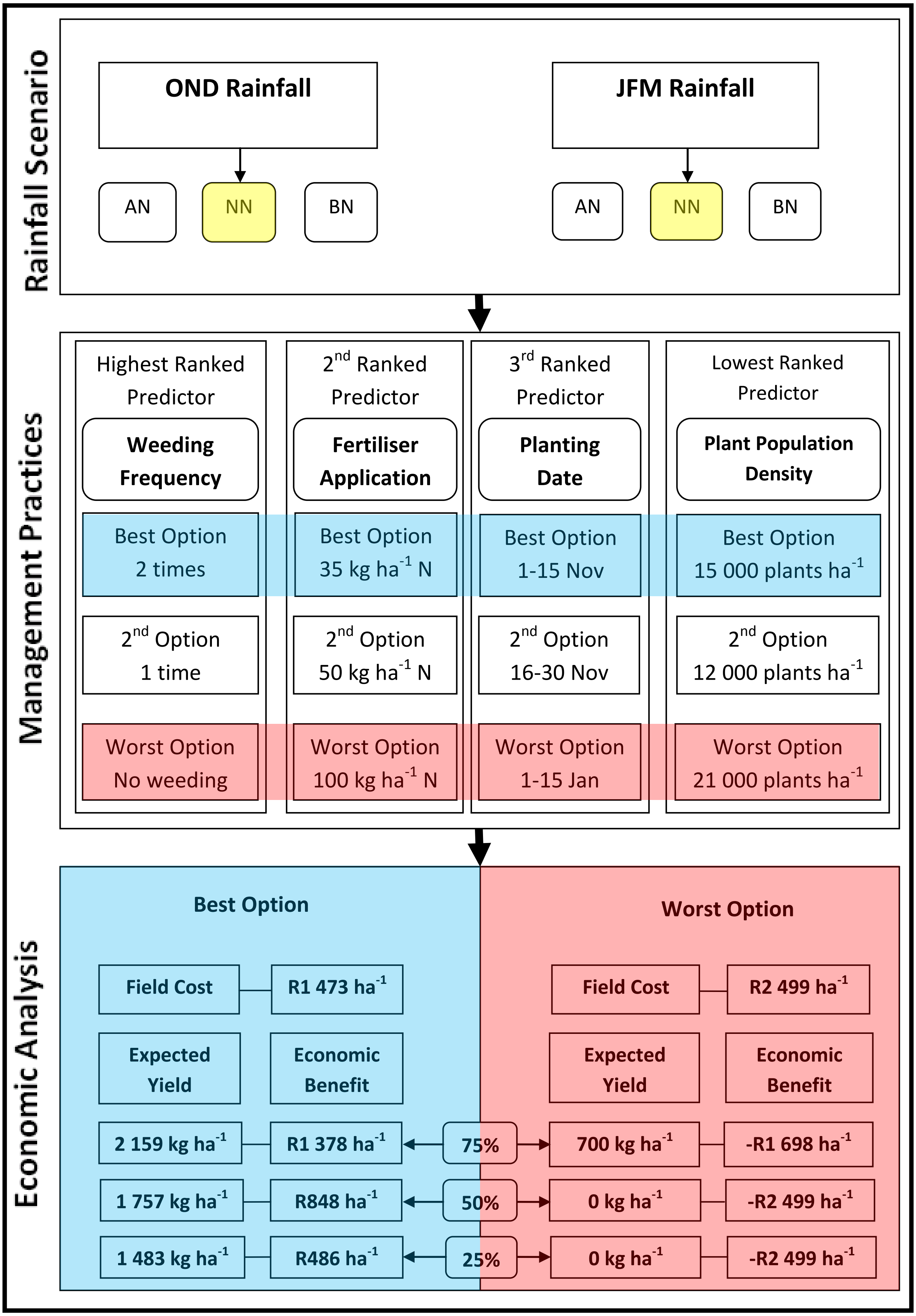


Figure 4.78: Flow chart of recommended practices for PAN 6479 during NN-NN rainfall conditions.

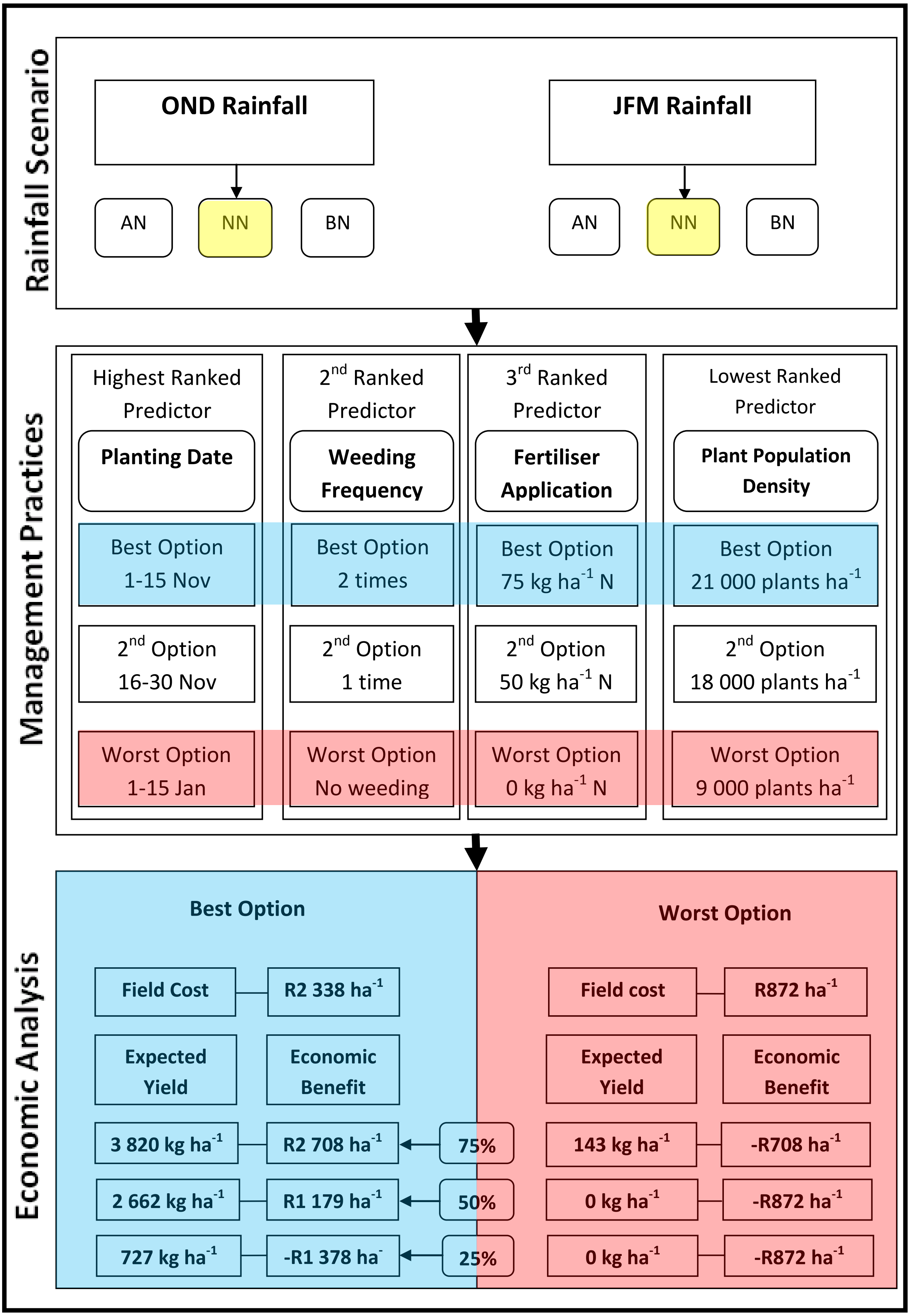


Figure 4.79: Flow chart of recommended practices for Pioneer 3237 during NN-NN rainfall conditions.

4.5.7 Recommended practices during near-normal followed by below-normal (NN-BN) rainfall conditions

The recommended management practices during NN-BN rainfall conditions for PAN 6479 and Pioneer 3237 were discussed in section 4.4.7. These practices are now summarised by flow charts in Figure 4.80 and Figure 4.81 for PAN 6479 and Pioneer 3237, respectively. The best set of management practices for PAN 6479 during NN-BN rainfall conditions involved weeding twice, planting during 16-30 November, applying 35 kg ha^{-1} N and using a plant population density of 12 000 plants ha^{-1}. As a result farmers would spend R1 424 ha^{-1} on field costs, while obtaining a yield of 1 410 kg ha^{-1} and a profit of R439 ha^{-1} at the 50% probability level. Weeding frequency was the highest yield contributor. The next best set of management practices for PAN 6479 involved weeding once in combination with the optimum values for the other management practices. The worst management decision was not to do any weeding control, planting during 1-15 January, applying 100 kg ha^{-1} N and 21 000 plants ha^{-1}. Farmers would then spend R2 499 ha^{-1} on field costs which resulted in losing everything (R2 499 ha^{-1}) due to crop failure under all three probability levels.

For Pioneer 3237 (Figure 4.81), during these seasonal rainfall conditions, the best set of management practices involved planting during 1-15 November, weeding thrice and applying 35 kg ha^{-1} N at a plant population density of 9 000 plants ha^{-1}. Farmers would spend R1 469 ha^{-1} on field costs, while obtaining a yield of 2 168 kg ha^{-1} and making a profit of R1 395 ha^{-1} at the 75% probability level. Since planting date was the most important yield contributor, the next best set of management practices for Pioneer 3237 involved planting during 16-30 November in combination with the optimum weeding frequency (3 times), fertiliser application rate (35 kg ha^{-1} N) and plant population density (9 000 plants ha^{-1}). The worst set of management practices involved planting during 1-15 January, not weeding at all, applying 100 kg ha^{-1} N and using 21 000 plants ha^{-1}. As a result farmers would spend R2 664 ha^{-1}on field costs due to an excessive plant population density and fertiliser application rate, and risk losing everything due to crop failure.

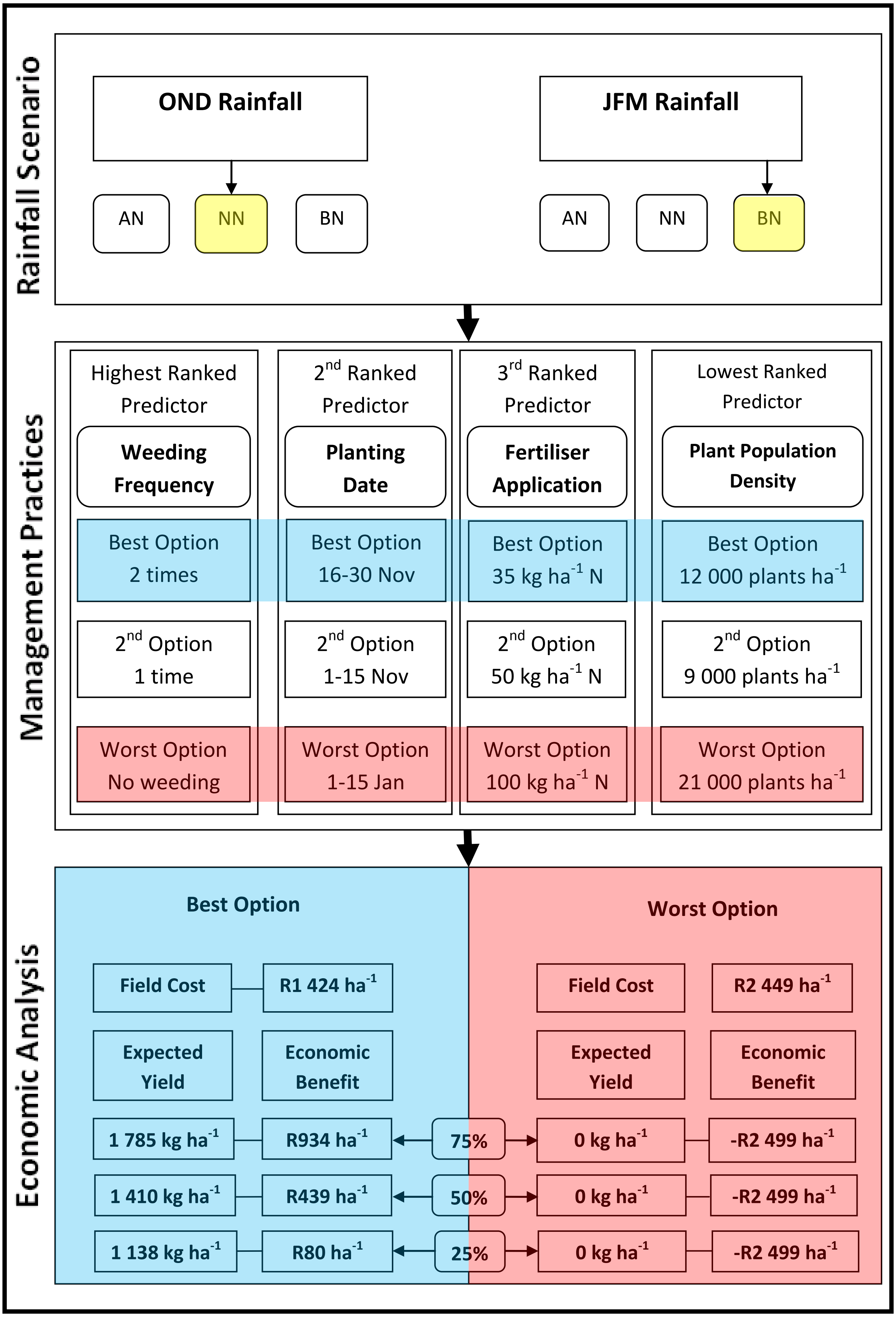


Figure 4.80: Flow chart of recommended practices for PAN 6479 during NN-BN rainfall conditions.

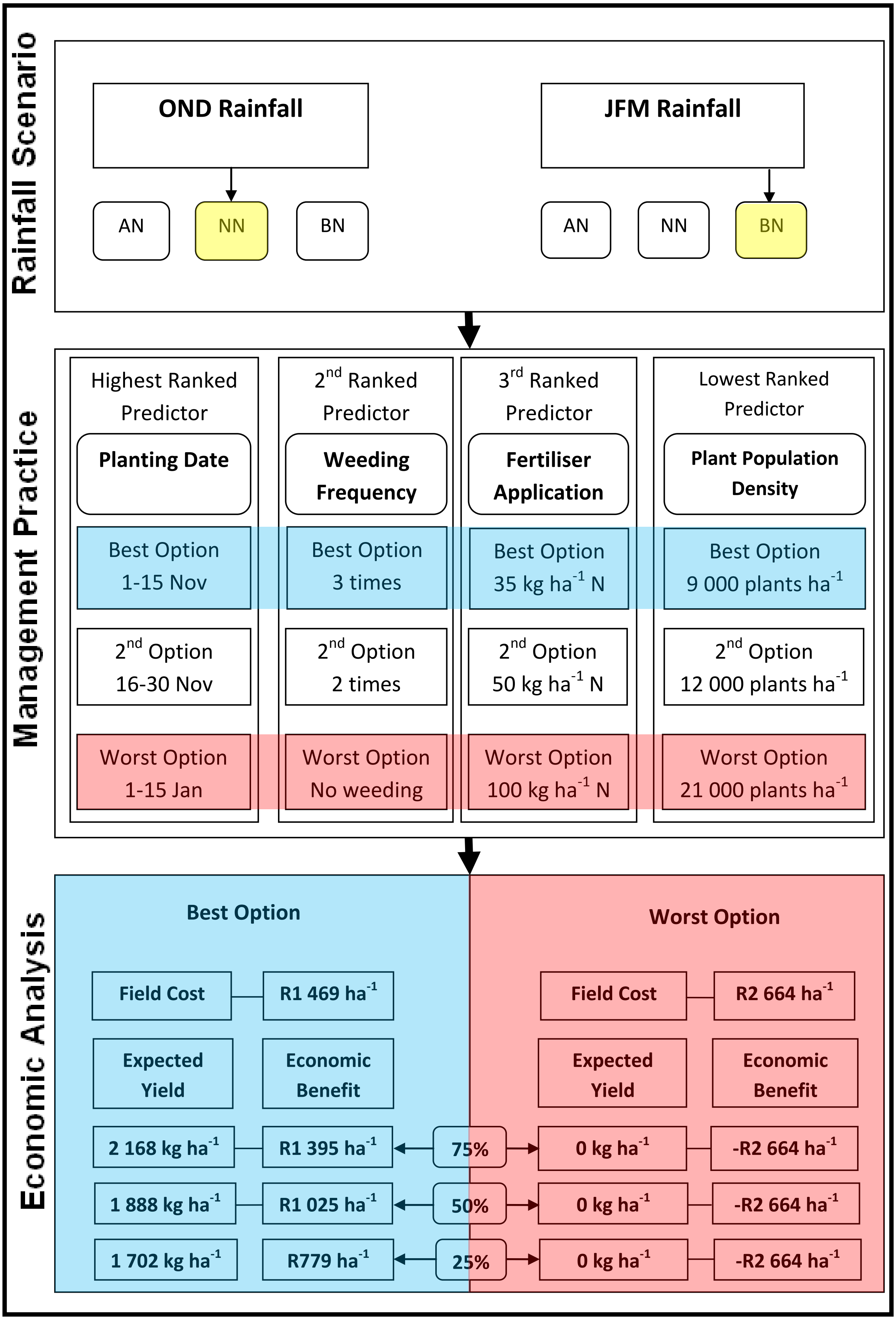


Figure 4.81: Flow chart of recommended practices for Pioneer 3237 during NN-BN rainfall conditions.

4.5.8 Recommended practices during below-normal followed by above-normal (BN-AN) rainfall conditions

The recommended management practices for PAN 6479 and Pioneer 3237 during BN-NN rainfall conditions were discussed in section 4.4.8. These practices are now summarised by the flow charts in Figure 4.82 and Figure 4.83. As indicated in Figure 4.82 the best set of management practices for PAN 6479 during these rainfall conditions involved a fertiliser application rate of 35 kg ha^{-1} N, planting during 1-15 November, weeding twice during the growth season and using a plant population density of 21 000 plants ha^{-1}. Fertiliser application rate was the highest yield contributor and the next best set of management practices under an alternative fertiliser application rate involved applying 50 kg ha^{-1} N in combination with the optimum planting date (1-15 November), weeding frequency (2 times) and plant population density (21 000 plants ha^{-1}). The worst set of management practices involved applying 100 kg ha^{-1} N, planting during 1-15 January, without weeding and using 9 000 plants ha^{-1}. The economic analysis illustrated a 75% probability of farmers obtaining R1 778 ha^{-1} under the best management practices after spending R1 573 ha^{-1} on field costs. Under the worst set of management practices farmers would spend R2 301 ha^{-1} on field costs and risk making a loss of R1 592 ha^{-1} at the same probability level.

The best set of management practices for Pioneer 3237 during BN-AN rainfall conditions involved planting during 1-15 November, applying 75 kg ha^{-1} N of fertiliser, weeding 3 times and planting 18 000 plants ha^{-1}. As a result the farmer would spend R2 289 ha^{-1} on field costs, while obtaining a yield of 3 226 kg ha^{-1} and making a profit of R1 973 ha^{-1} at the 50% probability level (Figure 4.83). When changing the planting date, the next best set of management practices involved planting during 16-30 November in combination with the optimum values for fertiliser application rate (75 kg ha^{-1} N), weeding frequency (3 times) and plant population density (18 000 plants ha^{-1}). The worst set of management practices was to plant during 1-15 January, applying 100 kg ha^{-1} N, without weeding and using 21 000 plants ha^{-1}. Farmer would then spend R2 664 ha^{-1} on field costs and risk losing everything due to crop failure at the 50% probability level.

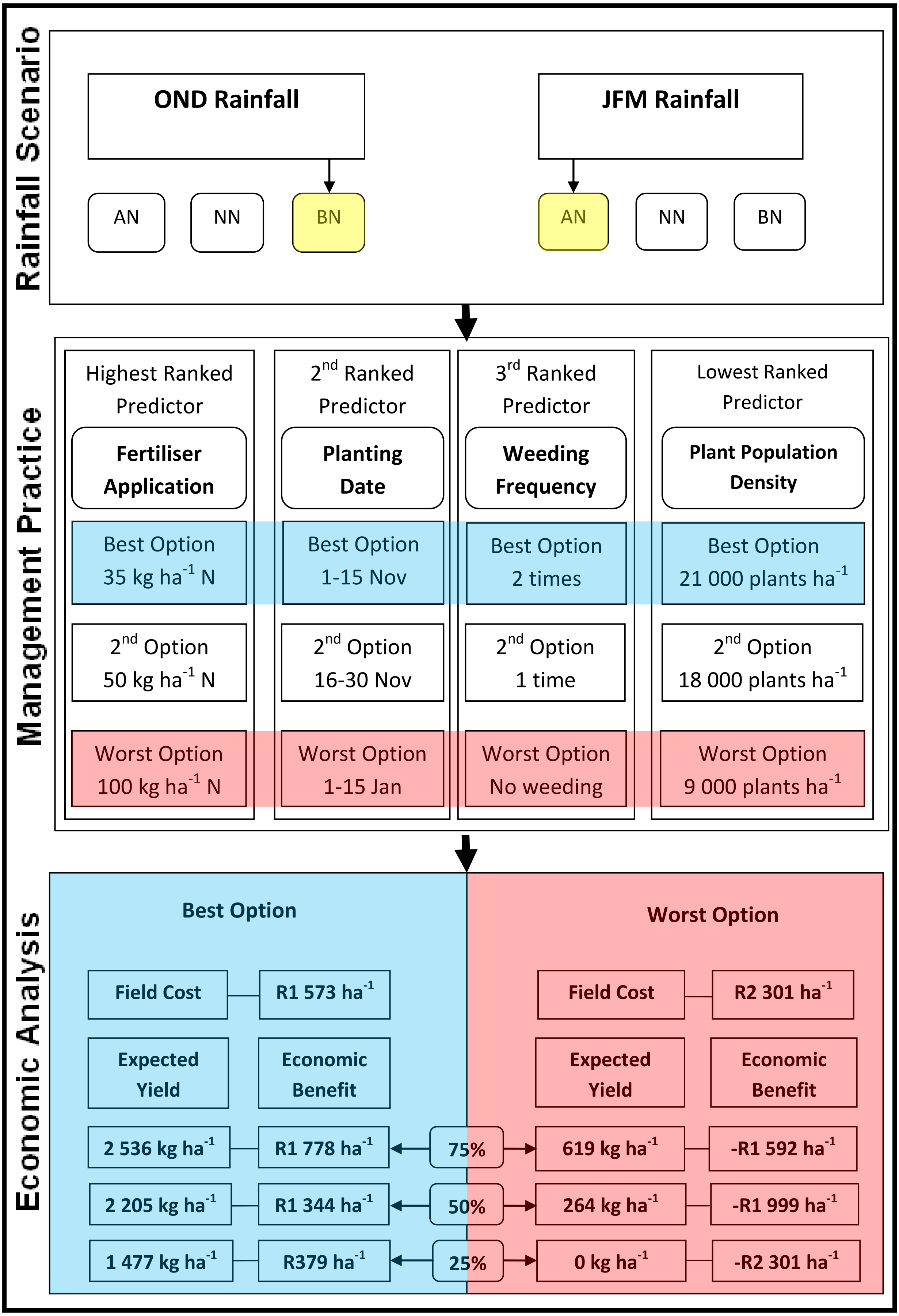


Figure 4.82: Flow chart of recommended practices for PAN 6479 during BN-AN rainfall conditions.

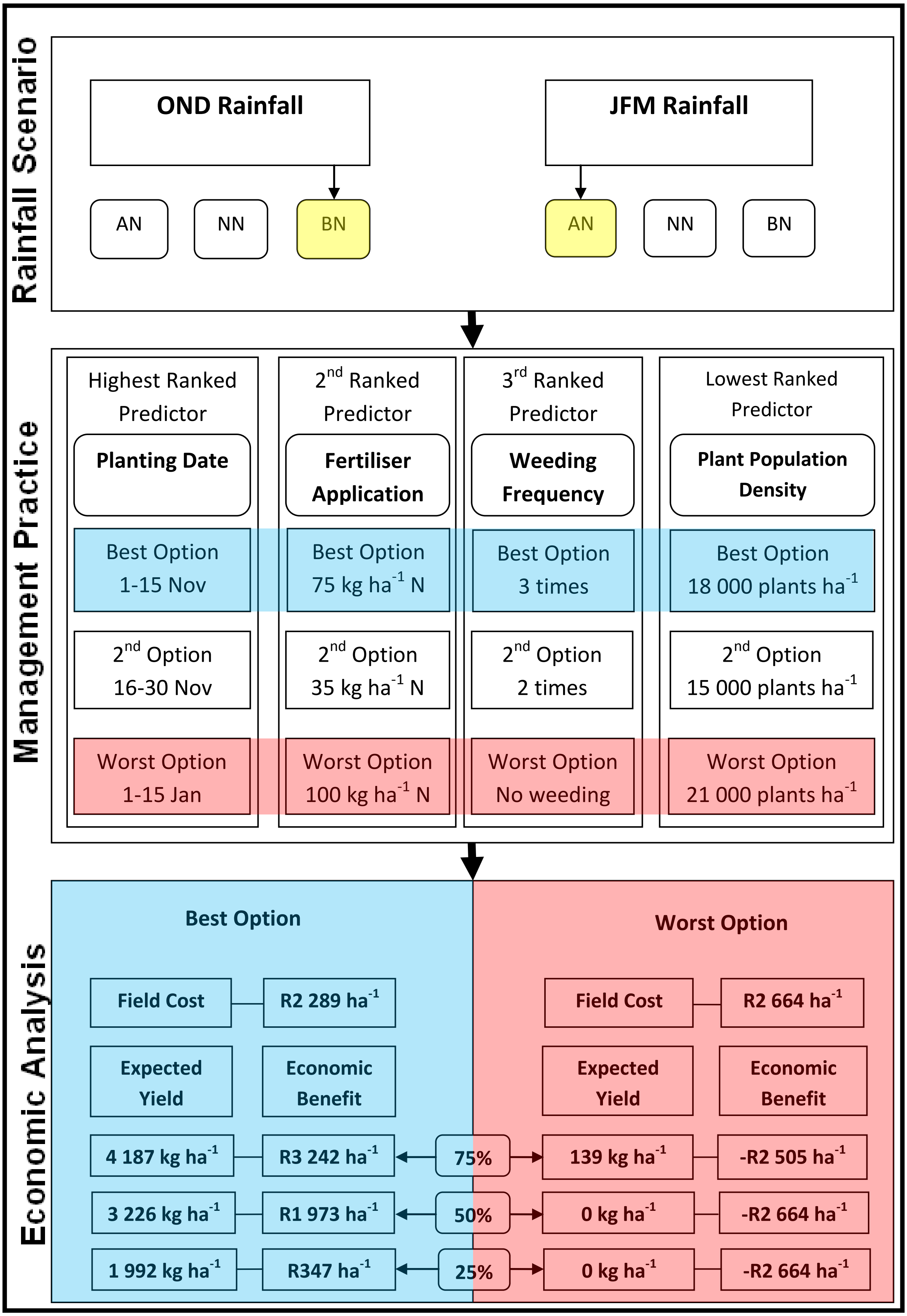


Figure 4.83: Flow chart of recommended practices for Pioneer 3237 during BN-AN rainfall conditions.

4.5.9 Recommended practices during below-normal followed by near-normal (BN-NN) rainfall conditions

The recommended management practices for PAN 6479 and Pioneer 3237 during BN-NN rainfall conditions were discussed in section 4.4.9. These practices are now summarised by the flow charts in Figure 4.84 and 4.85 for PAN 6479 and Pioneer 3237, respectively. As illustrated in Figure 4.84 the best set of management practices during BN-NN rainfall conditions involved planting during 1-15 November, weeding twice, using a fertiliser application rate of 35 kg ha^{-1} N and a plant population density of 15 000 plants ha^{-1}. As a result farmers would obtain a yield of 2000 kg ha^{-1} and make a profit of R1 169 ha^{-1} at the 75% probability level, after spending R1 474 ha^{-1} on field costs. Planting date was the most important yield contributor, so when changing the planting date to the next best set of management practices it involved planting 16-30 November and using optimum values of fertiliser application rate (35 kg ha^{-1} N), weeding frequency (3 times) and plant population density (15 000 plants ha^{-1}). The worst set of management practices involved planting during 1-15 January, not weeding at all and applying 100 kg ha^{-1} N of fertiliser using 21 000 plants ha^{-1}. Farmers would then obtain a yield of 21 kg ha^{-1} which resulted in a loss of R2 475 ha^{-1} at the same probability level.

For Pioneer 3237 (Figure 4.85) the best set of management practices during BN-NN rainfall conditions involved planting during 1-15 November, weeding thrice, applying 35 kg ha^{-1} N of fertiliser and planting 12 000 plants ha^{-1}. The economic analysis revealed a 50% probability of farmers obtaining a profit of R378 ha^{-1}, while the field costs amounted to R1 542 ha^{-1}. Since planting date was the highest yield contributor, the next best set of management practices involved planting 16-30 November with an optimum fertiliser application rate, weeding frequency and plant population density. The worst management practice involved planting during 1-15 January, no weeding practice, applying 100 kg ha^{-1} N of fertiliser and using 21 000 plants ha^{-1}. Farmers would spend R2 664 ha^{-1} and risk losing everything due to crop failure.

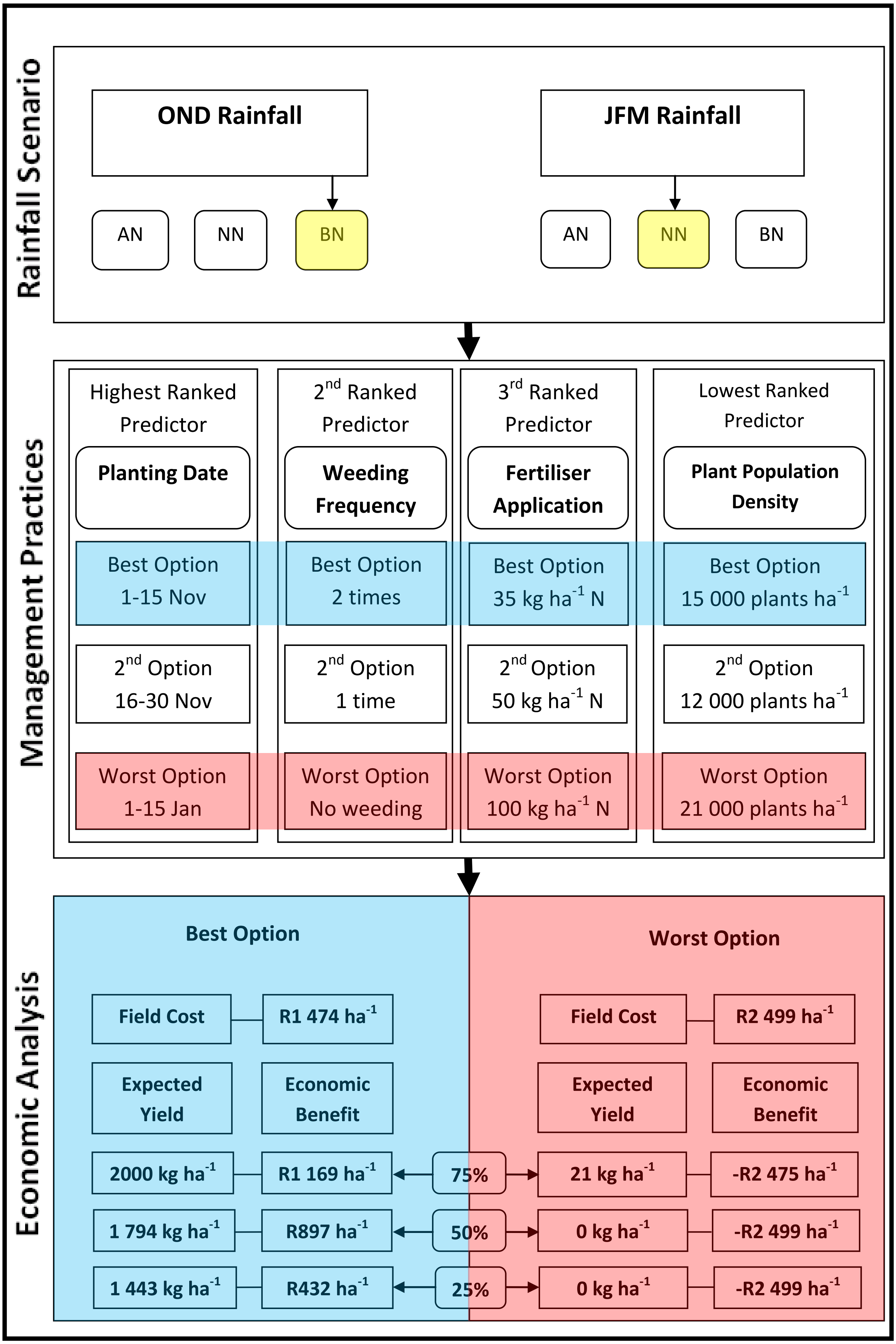


Figure 4.84: Flow chart of recommended practices for PAN 6479 during BN-NN rainfall conditions.

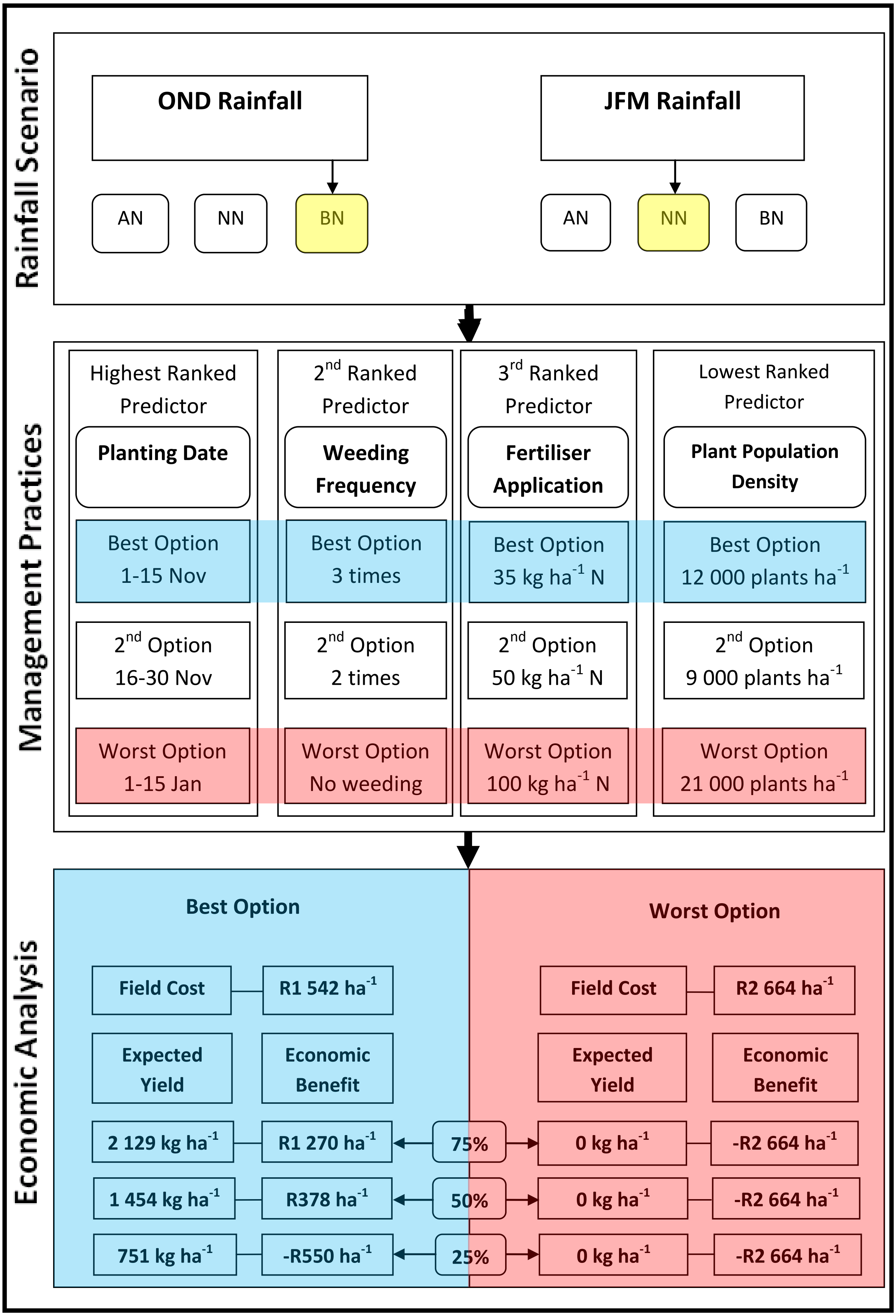


Figure 4.85: Flow chart of recommended practices for Pioneer 3237 during BN-NN rainfall conditions.

4.5.10 Recommended practices during below-normal followed by below-normal (BN-BN) rainfall conditions

The recommended management practices during BN-BN rainfall conditions for PAN 6479 and Pioneer 3237 were discussed in section 4.4.10. These practices are now summarised by the flow charts in Figure 4.86 (PAN 6479) and Figure 4.87 (Pioneer 3237). The best set of management practices for PAN 6479 involved planting 1-15 November, weeding twice, applying 35 kg ha^{-1} N and using a plant population density of 12 000 plants ha^{-1} (Figure 4.86). The economic analysis showed a 75% probability of farmers obtaining a profit of R709 ha^{-1}, after spending R1 424 ha^{-1} on field costs. Planting date was the highest yield contributor. When forced to choose an alternative date, the next best set of management practices for PAN 6479 involved planting 16-30 November and using the optimum weeding frequency, fertiliser application rate and plant population density (Table B17 in Appendix B). The worst set of management practices involved planting 1-15 January, not weeding, applying 100 kg ha^{-1} N of fertiliser and using 21 000 plants ha^{-1}. Farmers would spend R2 499 ha^{-1} and risk making a loss of R2 488 ha^{-1} at the 75% probability level.

During these dry conditions, the best set of management practices for Pioneer 3237 involved planting during 1-15 November, weeding twice, applying 35 kg ha^{-1} N and using a plant population density of 9 000 plants ha^{-1}. Farmers would then obtain a yield of 1 841 kg ha^{-1} and make a profit of R987 ha^{-1} at the 50% probability level, after spending R1 445 ha^{-1} on field costs (Figure 4.87). The next best set of management practices involved planting during 16-30 November with optimum values for the weeding frequency, fertiliser application rate, and plant population density. The worst set of management practices involved planting during 1-15 January, not weeding, applying 100 kg ha^{-1} N of fertiliser and using 21 000 plants ha^{-1}. Farmers would then experience crop failure which resulted in a loss of R2 664 ha^{-1}.

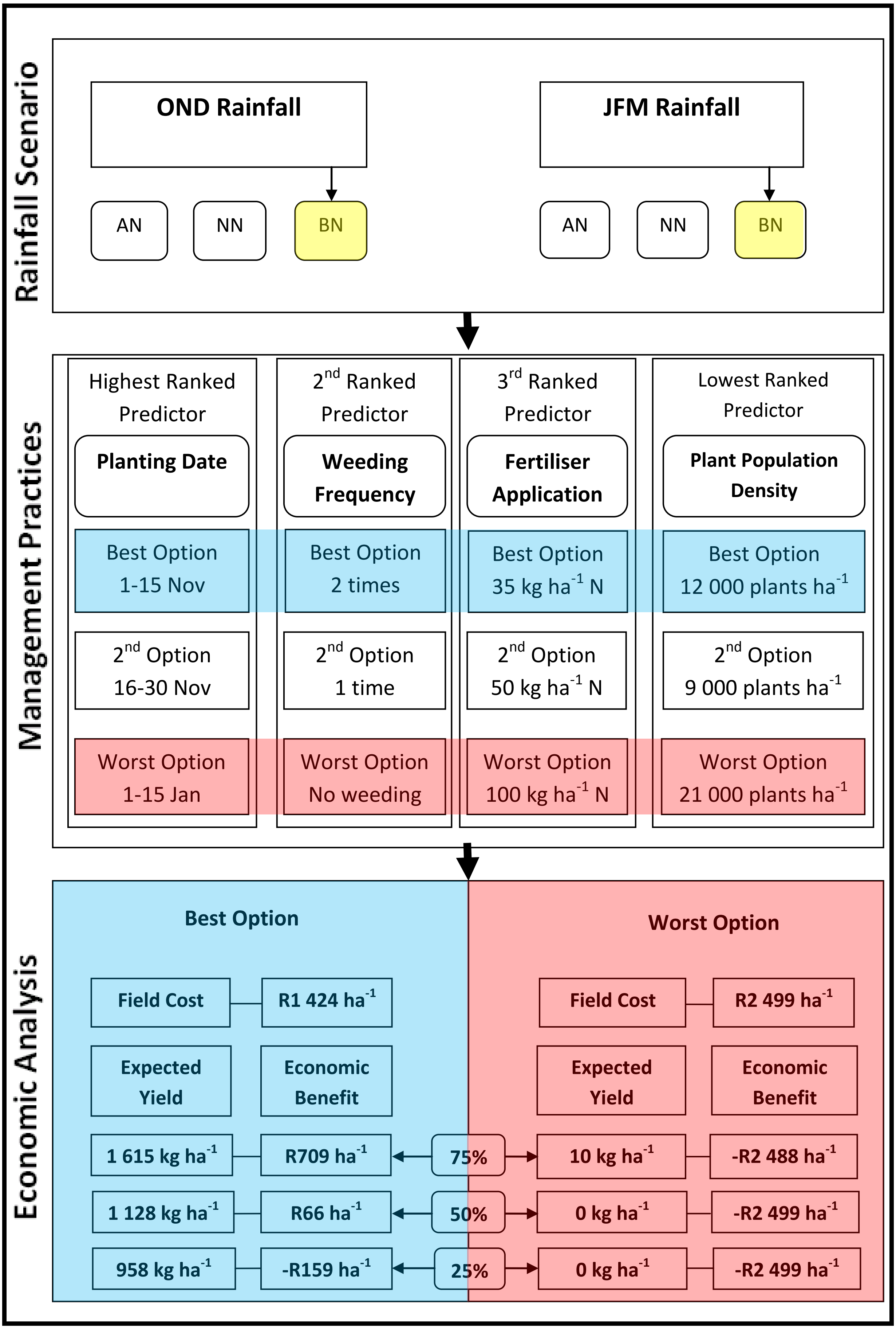


Figure 4.86: Flow chart of recommended practices for PAN 6479 during BN-BN rainfall conditions.

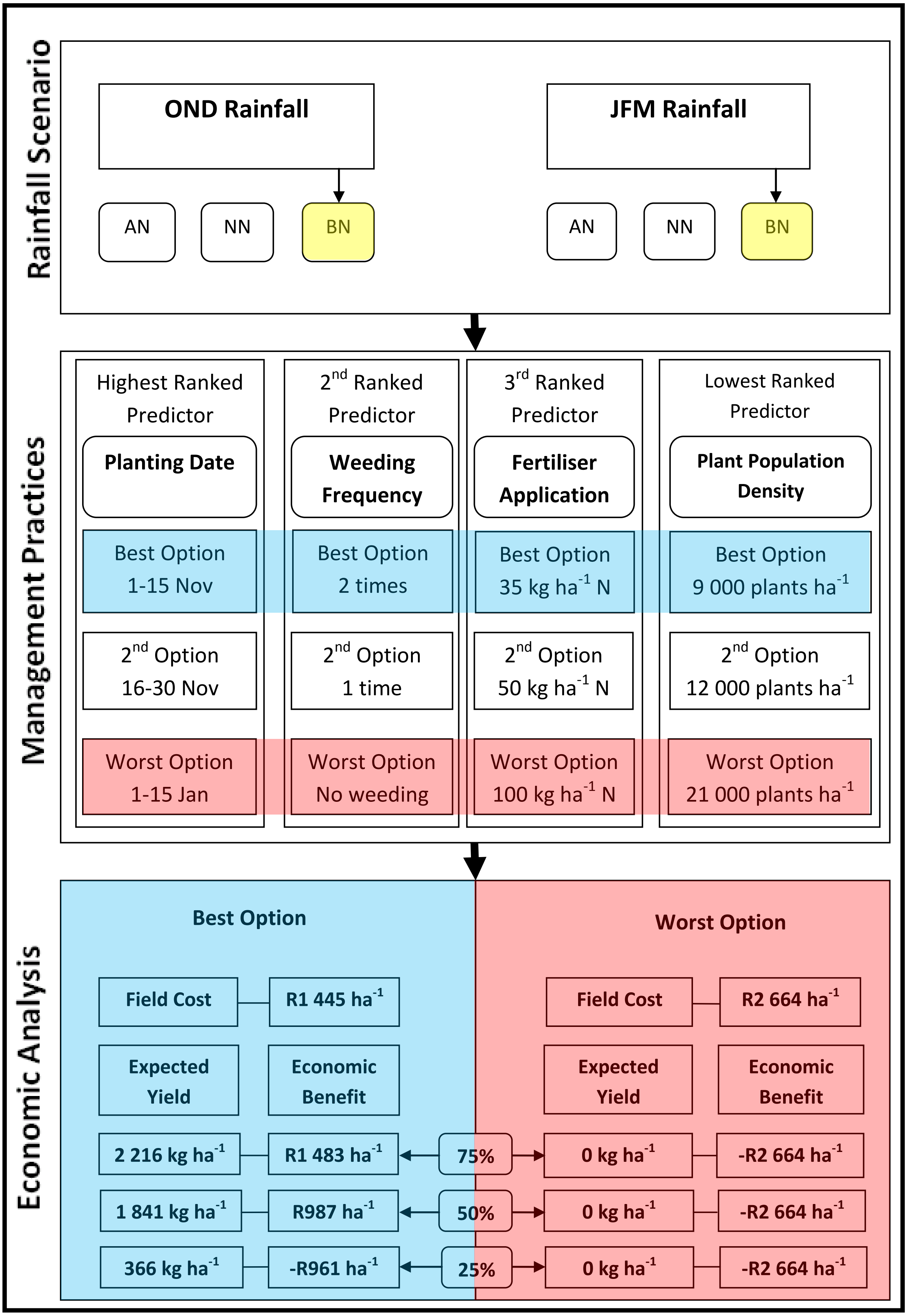


Figure 4.87: Flow chart of recommended practices for Pioneer 3237 during BN-BN rainfall conditions.

In summary, the Modder River catchment is characterised by erratic rainfall conditions with a high evapotranspiration. The climate analysis (presented in section 4.1) indicated that more than 80% of annual rainfall in the catchment occurs during October to March. The variability in seasonal rainfall has a major influence on rainfed maize production.

Validation revealed that, under the recommended management practices used in the central Free State, APSIM performed better for PAN 6479 (medium growing cultivar) than Pioneer 3237 (short 3growing cultivar). In most cases, the simulated maize yields managed to mimic the increasing or decreasing trends observed in the measured yields.

After validation, the crop growth model was successfully used to simulate maize yields under different management practices for both cultivars. Analysis of these results (presented in section 4.3) made it possible to identify those predictors that made a significant contribution to the maize yield under various seasonal rainfall conditions. The economic analysis (presented in section 4.4) was done to assess the financial implications of the potential management practices. This made it possible to identify the most profitable set of management practices under various seasonal rainfall conditions. This information was subsequently used to develop the advisory practices for small-scale farmers (presented in section 4.5). Armed with such guidance these farmers could drastically increase their long term sustainability in rainfed maize production.

CHAPTER 5 CONCLUSIONS

Global food security is threatened by a rising world population. There is a need to increase agricultural production, particularly in semi-arid regions like South Africa, where it is often lower than the land's potential. Climate variability (e.g. erratic rainfall during the crop growth season) is a major constraining factor for agricultural production. Maize, which is grown as a staple food in many areas, is no exception to this problem. The economic future of maize production could potentially be safeguarded by reducing the risk associated with climate variability, especially on a seasonal scale. Skilful seasonal rainfall forecasts are made available by several climate forecasting groups. Farmers can take advantage of these forecasts to increase maize production by altering management practices. However, farmers need assistance with the interpretation of seasonal rainfall forecasts and how to improve maize production through adjusting management practices.

In the Modder River catchment, maize is grown during the summer rainfall season (October to March). It was found that the average annual rainfall total for the quaternary catchments considered in this study range between 442 and 532 mm, while the annual crop-evaporation is more than 1 400 mm. The bulk of summer rainfall occurred during January-March (JFM) for all QCs. During wet seasons (AN-AN conditions) the expected rainfall totals were more than 204.0 and 267.5 mm for OND and JFM, respectively. During dry seasons (BN-BN conditions) the expected rainfall totals were less than 101.0 and 147.5 mm for OND and JFM, respectively. Of the 196 growing seasons considered, it was not surprising to find that the bulk of the analogue seasons fell in the NN-NN category (28), with lower frequencies for the more extreme rainfall seasons (19 for AN-AN and 17 for BN-BN).

Crop growth models like APSIM have been used successfully in southern Africa to simulate maize yields under different environmental conditions (e.g. Carberry *et al.,* 2002; Shamudzarira & Robertson, 2002; Dimes & Du Toit, 2009; Ncube *et al.,* 2009; Whitbread *et al.,* 2010). Validation of APSIM over the study area was important because of the proposed application to real-world problems. The model simulated PAN 6479 better than Pioneer 3237 under different management practices. The highest coefficient of determination (R^2) between measured and simulated maize yields for PAN 6479 was 0.66, while for Pioneer 3237 the R^2 was 0.42. APSIM also managed to simulate low yields during extreme climatic events like flood or drought seasons for PAN 6479. The influence of a series of recurring droughts in the 1990s (associated with the El Niño phenomenon) was also captured by APSIM. The best simulated results were achieved using 18 000 plants ha^{-1} with 100 kg ha^{-1} N, weeding thrice and planting during the period of 1-15 November. Under this set of management practices the R^2 = 0.66, D-index = 0.89, modelling efficiency = 0.59 and RMSEu/RMSE = 0.88. For Pioneer 3237 the model over-estimated the maize yields, particularly during drought seasons, while the modelling efficiency under different management practices was consistently negative.

Simulation of yields clearly showed the effect of different seasonal rainfall conditions and management practices on rainfed maize production. Planting date ranked highest among maize yield predictors (except for AN-NN, AN-BN, NN-NN, NN-BN and BN-AN rainfall conditions for PAN 6479). In general, the simulations indicated that it is usually better to plant early regardless of the seasonal rainfall scenarios. This is somewhat discerning, since one would expect to delay planting during dry seasons in order to avoid water stress during critical crop growth stages such as tasselling.

Weeding frequency ranked highest during AN-NN, AN-BN, NN-BN and BN-AN rainfall seasons for PAN 6479, while for Pioneer 3237 it ranked second except when AN rainfall conditions occurred during the second half of the season. Fertiliser application rate ranked second when AN rainfall is occurring during the second half of the seasons for both cultivars, but ranked highest during NN-NN seasons for PAN 6479. For both cultivars maize yields were significantly reduced when no weeding or fertiliser was applied. The optimum fertiliser application rate that produced higher maize yields for PAN 6479 during different seasonal rainfall conditions varied between 35 and 50 kg ha^{-1} N, while the optimum weeding frequency was 2 times. For Pioneer 3237, the optimum weeding frequency varied between 2 and 3 times, while optimum fertiliser application rate varied from 75 to 35 kg ha^{-1} N as rainfall conditions varied from AN to BN.

During different seasonal rainfall scenarios plant population density was always ranked the lowest predictor for both cultivars. This indicated that the contribution of varying plant population densities to maize yield was minor. For both cultivars higher maize yields were produced under a maximum plant population density (21 000 plants ha^{-1}) during AN-AN rainfall conditions. During NN-NN conditions the optimum plant population density varied between 15 000 and 21 000 plants ha^{-1} for PAN 6479 and Pioneer 3237, respectively. One concern was that during AN-NN seasons the model indicated higher yields for Pioneer 3237 when using low plant population densities, while higher plant population densities are usually expected to perform better under such good rainfall conditions. During BN-BN rainfall seasons the optimum plant population density was 12 000 and 9 000 plants ha^{-1} for PAN 6479 and Pioneer 3237, respectively. During wet seasons under optimum management practices the expected maize yields could exceed 3 000 and 5 000 kg ha^{-1} for PAN 6479 and Pioneer 3237, respectively. During dry seasons the maize yields was consistently below 1 700 and 2 700 kg ha^{-1} for PAN 6479 and Pioneer 3237, respectively.

The results of the economic analysis revealed that the highest yielding set of management practices was not necessarily always the most profitable option. Tables 5.1 and 5.2 summarise the best set of management practices under each seasonal rainfall scenario for PAN 6479 and Pioneer 3237, respectively. The breakdown of economic analysis is also provided with the expected yield and economic benefit corresponding to 50% probability level. Once again it became clear that planting early (November) is most profitable under all seasonal rainfall scenarios. It was evident that a high plant population density resulted in higher profit when AN conditions occurred during the second half of the growing season. On the other hand, lower plant population densities proved optimal when the second half of the rainfall season was BN. Interestingly, applying 75 kg ha^{-1} N never formed part of the management practices summarised in Table 5.1 for PAN 6479. Only during AN-AN and NN-AN seasons the optimum fertiliser application rate was found to be 50 kg ha^{-1} N, otherwise 35 kg ha^{-1} N sufficed.

Generally speaking, for Pioneer 3237 higher fertiliser application rates (50 to 75 kg ha^{-1} N) were required. However, during any BN and NN combination the optimum fertiliser application rate was 35 kg ha^{-1} N (Table 5.2). The optimum weeding frequency was twice for PAN 6479, but twice or thrice for Pioneer 3237.

For BN-NN and BN-BN rainfall conditions, the management practices farmers should avoid at all costs for both cultivars were to plant during 1-15 January, using 21 000 plants ha^{-1}, applying 100 kg ha^{-1}N of fertiliser and not to weed at all. During BN-BN conditions farmers would spend R2 449 ha^{-1} and risk making a loss of R2 488 ha^{-1} at the 75% probability level for PAN 6479. For Pioneer 3237 farmers would spend R2 664 ha^{-1} and risk losing everything due to crop failure.

Table 5.1: Summary of best management practices with their economic analysis under different seasonal rainfall scenarios for PAN 6479

Rainfall Scenario	Management Practices				Economic Analysis		
	Planting Date	**Plant Population Density (plants ha^{-1})**	**Fertiliser application rate (kg ha^{-1} N)**	**Weeding Frequency**	**Field Cost (R ha^{-1})**	**Expected Yield (50%) (kg ha^{-1})**	**Economic Benefit (50%) (R ha^{-1})**
AN-AN	16-30 Nov	21 000	50	2	1 798	2 854	1 972
AN-NN	16-30 Nov	21 000	35	2	1 572	1 814	823
AN-BN	16-30 Nov	15 000	35	2	1 473	1 660	719
NN-AN	16-30 Nov	21 000	50	2	1 798	2 940	2 086
NN-NN	1-15 Nov	15 000	35	2	1 473	1 757	848
NN-BN	16-30 Nov	12 000	35	2	1 424	1 410	439
BN-AN	1-15 Nov	21 000	35	2	1 573	2 205	1 344
BN-NN	1-15 Nov	15 000	35	2	1 474	1 794	897
BN-BN	1-15 Nov	12 000	35	2	1 424	1 128	66

Table 5.2: Summary of best management practices with their economic analysis under different seasonal rainfall scenarios for Pioneer 3237

Rainfall Scenario	Management Practices				Economic Analysis		
	Planting Date	Plant Population Density (plants ha^{-1})	Fertiliser application rate (kg ha^{-1} N)	Weeding Frequency	Field Cost (R ha^{-1})	Expected Yield (50%) (kg ha^{-1})	Economic Benefit (50%) (kg ha^{-1})
AN-AN	1-15 Nov	18 000	75	2	2 338	4 232	3 253
AN-NN	1-15 Nov	12 000	75	3	2 142	3 686	2 726
AN-BN	1-15 Nov	9 000	50	3	1 694	2 352	1 412
NN-AN	1-15 Nov	18 000	75	3	2 289	3 824	2 763
NN-NN	1-15 Nov	21 000	75	2	2 338	2 662	1 179
NN-BN	1-15 Nov	9 000	35	3	1 469	1 888	1 025
BN-AN	1-15 Nov	18 000	75	3	2 289	3 226	1 973
BN-NN	1-15 Nov	12 000	35	3	1 542	1 454	378
BN-BN	1-15 Nov	9 000	35	2	1 445	1 841	987

The management practices provided in the type of advisories developed in this study for various seasonal rainfall scenarios could assist small-scale maize farmers to increase their yields and maximise the associated profit under rainfed conditions. The use of a cropping systems model to add value to the seasonal rainfall forecast (as provided by SAWS) is deemed appropriate as it best captures the complex interactions between climate and management practices to affect yield outcomes. Unfortunately, site-specific calibration of APSIM is required against observed sets of climate, soil and yield data for which the associated management practices are known before these advisories can be used by extension officers to advise small-scale farmers within the Modder River catchment. Since a relationship has already been established, a golden opportunity exists to let suitable intermediary institutions (like the ARC) use these advisory flow charts in training workshops for the agricultural extension officers within the Modder River catchment.

One recommendation is therefore for future research to include conducting a “sensibility” analysis that incorporate the typical range of management practices used in this area and their associated expected yields. Field trials could also be conducted to aid in both model calibration as well as training of the agricultural extension officers. The field trials may be set up in accordance with the seasonal rainfall conditions using the best, second best and worst sets of management practices in order to demonstrate their influence on the maize yield. However, this option is likely to be costly and labour intensive.

Future research should also focus on setting up APSIM for the soil types, cultivars and even crops (e.g. wheat, sorghum and sunflower) grown in other areas of South Africa. Similar advisories can be developed for these crops and regions. A well tested model can also be used to simulate the effect of climate change on rainfed crop production in South Africa, thereby safeguarding food security for future generations.

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APPENDIX A

Table A1: The combinations of management practices that provided higher yields for PAN 6479 during AN-AN rainfall conditions

Management practices			
Planting date	**Plant population density (plants ha^{-1})**	**Fertiliser application rate (kg ha^{-1} N)**	**Weeding frequency**
1-15 November	9 000	35	1;2
1-15 November	12 000	35	1;2
1-15 November	15 000	35	1
1-15 November	15 000	50	2
1-15 November	18 000	35;50	2
1-15 November	21 000	50	2
16-30 November	9 000	35	1;2
16-30 November	12 000	35	1;2
16-30 November	15 000	35	1
16-30 November	15 000	50	2
16-30 November	18 000	35	1;2
16-30 November	18 000	50	2
16-30 November	21 000	35	1;2
16-30 November	21 000	50	2
1-15 December	9 000	35	1;2
1-15 December	12 000	35	1;2
1-15 December	15 000	35	1
1-15 December	15 000	50	2
1-15 December	18 000	35	1;2
1-15 December	18 000	50	2
1-15 December	21 000	35	1;2
1-15 December	21 000	50	2

Table A2: The combinations of management practices that provided higher yields for Pioneer 3237 during AN-AN rainfall conditions

Management practices			
Planting date	**Plant population density (plants ha^{-1})**	**Fertiliser application rate (kg ha^{-1} N)**	**Weeding frequency**
1-15 November	9 000	35;50;75	2
1-15 November	12 000	35;50;75	2
1-15 November	15 000	50;75	2
1-15 November	18 000	50;75	2
1-15 November	21 000	75	2
16-30 November	9 000	50	1
16-30 November	9 000	75	2
16-30 November	12 000	75	2
16-30 November	15 000	50	1
16-30 November	15 000	75	2
16-30 November	18 000	35;50	1
16-30 November	18 000	75	2
16-30 November	21 000	35;50	1
16-30 November	21 000	75	2

Table A3: The combinations of management practices that provided higher yields for PAN 6479 during AN-NN rainfall conditions

Management practices			
Planting date	**Plant population density (plants ha^{-1})**	**Fertiliser application rate (kg ha^{-1} N)**	**Weeding frequency**
1-15 November	9 000	35	1;2
1-15 November	12 000	35	1;2
1-15 November	15 000	35	1;2
1-15 November	15 000	50	2
1-15 November	18 000	35	1;2
1-15 November	21 000	35	1;2
1-15 November	21 000	50	2
16-30 November	9 000	35	1;2
16-30 November	12 000	35	1;2
16-30 November	15 000	35	1;2
16-30 November	15 000	50	2
16-30 November	18 000	35	1;2
16-30 November	18 000	50	2
16-30 November	21 000	35;50	1;2
1-15 December	9 000	35	1;2
1-15 December	12 000	35	1;2
1-15 December	15 000	35	1;2
1-15 December	15 000	50	2
1-15 December	18 000	35	3
1-15 December	21 000	35	3

Table A4: The combinations of management practices that provided higher yields for Pioneer 3237 during AN-NN rainfall conditions

Management practices			
Planting date	**Plant population density (plants ha^{-1})**	**Fertiliser application rate (kg ha^{-1} N)**	**Weeding frequency**
1-15 November	9 000	35	1;2
1-15 November	9 000	50	1;2;3
1-15 November	9 000	75	2;3
1-15 November	12 000	50	2;3
1-15 November	12 000	75	2;3
1-15 November	21 000	75	3
16-30 November	9 000	35	1;2
16-30 November	9 000	50	1;2;3
16-30 November	9 000	75	2;3
16-30 November	12 000	35;50	2
16-30 November	12 000	50	3
16-30 November	12 000	75	2;3
16-30 November	15 000	35;50	2
16-30 November	15 000	50	3
16-30 November	15 000	75	2;3
1-15 December	9 000	35	1;2
1-15 December	9 000	50	1;2;3
1-15 December	9 000	75	2;3
1-15 December	12 000	35	1;2
1-15 December	12 000	50	1;2;3
1-15 December	12 000	75	1;2;3
1-15 December	15 000	35	1;2
1-15 December	15 000	50	1;2;3
1-15 December	15 000	75	2;3

Table A5: The combinations of management practices that provided higher yields for PAN 6479 during AN-BN rainfall conditions

Management practices			
Planting date	**Plant population density (plants ha^{-1})**	**Fertiliser application rate (kg ha^{-1} N)**	**Weeding frequency**
1-15 November	9 000	35	1;2
1-15 November	12 000	35	1;2
1-15 November	15 000	35	1;2
1-15 November	18 000	35	1;2
16-30 November	9 000	35	1;2
16-30 November	12 000	35	1;2
16-30 November	15 000	35	1;2
16-30 November	18 000	35	1;3
16-30 November	21 000	35	3
1-15 December	9 000	35	1;2
1-15 December	12 000	35	1;2

Table A6: The combinations of management practices that provided higher yields for Pioneer 3237 during AN-BN rainfall conditions

Management practices			
Planting date	**Plant population density (plants ha^{-1})**	**Fertiliser application rate (kg ha^{-1} N)**	**Weeding frequency**
1-15 November	9 000	35	2;3
1-15 November	9 000	50;75	3
16-30 November	9 000	35	3
16-30 November	9 000	50;75	3
16-30 November	12 000	35	1;2
16-30 November	12 000	50	2
16-30 November	12 000	75	3

Table A7: The combinations of management practices that provided higher yields for PAN 6479 during NN-AN rainfall conditions

Management practices			
Planting date	**Plant population density (plants ha^{-1})**	**Fertiliser application rate (kg ha^{-1} N)**	**Weeding frequency**
1-15 November	9 000	35	1;2
1-15 November	12 000	35	1;2
1-15 November	15 000	35	1;2
1-15 November	15 000	50	1;2
1-15 November	18 000	35	1;2
1-15 November	18 000	50	1;2
1-15 November	21 000	35	1;2
1-15 November	21 000	50	1;2
16-30 November	9 000	35	1;2
16-30 November	12 000	35	1;2
16-30 November	12 000	50	1
16-30 November	15 000	35	1;2
16-30 November	15 000	50	1;2
16-30 November	18 000	35	1;2
16-30 November	18 000	50	1;2
16-30 November	21 000	35	1;2
16-30 November	21 000	50	1;2
1-15 December	9 000	35	1;2
1-15 December	12 000	35	1;2
1-15 December	12 000	50	1

1-15 December	15 000	35	1;2
1-15 December	15 000	50	1;2
1-15 December	18 000	35	1;2
1-15 December	18 000	50	1;2
1-15 December	21 000	35	1;2
1-15 December	21 000	50	1;2

Table A8: The combinations of management practices that provided higher yields for Pioneer 3237 during NN-AN rainfall conditions

Management practices			
Planting date	**Plant population density (plants ha^{-1})**	**Fertiliser application rate (kg ha^{-1} N)**	**Weeding frequency**
1-15 November	9 000	35	2
1-15 November	9 000	50	2;3
1-15 November	9 000	75	2
1-15 November	12 000	35;50;75	2;3
1-15 November	15 000	35;50;75	2;3
1-15 November	18 000	35;50;75	2;3
1-15 November	21 000	35;50;75;100	2;3
16-30 November	9 000	35	2
16-30 November	9 000	50	2;3
16-30 November	9 000	75	2
16-30 November	12 000	35;50;75	2;3
16-30 November	15 000	35;50;75	2;3
16-30 November	18 000	35;50;75	2;3
16-30 November	21 000	35;50;75;100	2;3
1-15 December	9 000	35	2
1-15 December	9 000	50	2;3
1-15 December	9 000	75	2
1-15 December	12 000	35;50;75	2;3
1-15 December	15 000	35;50;75	2;3
1-15 December	18 000	35;50;75	2;3
1-15 December	21 000	35;50;75;100	2;3

Table A9: The combinations of management practices that provided higher yields for PAN 6479 during NN-NN rainfall conditions

Management practices			
Planting date	**Plant population density (plants ha^{-1})**	**Fertiliser application rate (kg ha^{-1} N)**	**Weeding frequency**
1-15 November	9 000	35	1;2
1-15 November	12 000	35	1;2
1-15 November	12 000	50	3
1-15 November	15 000	35	1;2
1-15 November	15 000	50	1;2
1-15 November	18 000	35	1;2
1-15 November	18 000	50	2
1-15 November	21 000	35	1;2
16-30 November	9 000	35	1;2
16-30 November	12 000	35	1;2
16-30 November	12 000	50	3
16-30 November	15 000	35	1;2
16-30 November	15 000	50	2;3
16-30 November	18 000	35	1;2
16-30 November	18 000	50	2
16-30 November	21 000	35	1;2

16-30 November	21 000	50	2
1-15 December	9 000	35	1;2
1-15 December	12 000	35	1;2
1-15 December	12 000	50	3
1-15 December	15 000	35	1;2
1-15 December	15 000	50	3
1-15 December	18 000	35	1;2
1-15 December	21 000	35	1;2
1-15 December	21 000	50	2;3

Table A10: Combinations of management practices that provided higher yields for Pioneer 3237 during NN-NN rainfall conditions

Management practices			
Planting date	**Plant population density (plants ha^{-1})**	**Fertiliser application rate (kg ha^{-1} N)**	**Weeding frequency**
1-15 November	9 000	35	1;2
1-15 November	12 000	35;50	2
1-15 November	15 000	35;50;75	2
1-15 November	18 000	35;50;75	2
1-15 November	21 000	35	1;2
1-15 November	21 000	50;75	2
16-30 November	9 000	35	1;2
16-30 November	12 000	50;70	2
16-30 November	18 000	75;100	2
16-30 November	21 000	35	1
16-30 November	21 000	75	2

Table A11: Combinations of management practices that provided higher yields for PAN 6479 during NN-BN rainfall conditions

Management practices			
Planting date	**Plant population density (plants ha^{-1})**	**Fertiliser application rate (kg ha^{-1} N)**	**Weeding frequency**
1-15 November	9 000	35	1;2
1-15 November	12 000	35	1;2
1-15 November	15 000	35	1;2
1-15 November	15 000	50	2
1-15 November	18 000	35	1;2
1-15 November	21 000	35	2
16-30 November	9 000	35	1;2
16-30 November	12 000	35	2
16-30 November	15 000	35	2
16-30 November	15 000	50	1
16-30 November	18 000	35	2
16-30 November	21 000	35	2

Table A12: Combinations of management practices that provided higher yields for Pioneer 3237 during NN-BN rainfall conditions

Management practices			
Planting date	**Plant population density (plants ha^{-1})**	**Fertiliser application rate (kg ha^{-1} N)**	**Weeding frequency**
1-15 November	9 000	35	1;2
1-15 November	9 000	50	3
1-15 November	12 000	50	2;3
16-30 November	9 000	35	1;2
16-30 November	9 000	50	3
16-30 November	12 000	50	2;3
16-30 November	21 000	35	2

Table A13: Combinations of management practices that provided higher yields for PAN 6479 during BN-AN rainfall conditions

Management practices			
Planting date	**Plant population density (plants ha^{-1})**	**Fertiliser application rate (kg ha^{-1} N)**	**Weeding frequency**
1-15 November	12 000	35	1;2
1-15 November	15 000	35	1;2
1-15 November	15 000	50	1;2
1-15 November	18 000	35	1;2
1-15 November	18 000	50	1;2
1-15 November	21 000	35	1;2
1-15 November	21 000	50	1;2
1-15 November	21 000	75	1;2
16-30 November	12 000	35	1;2
16-30 November	12 000	50	1;2
16-30 November	15 000	35	1;2
16-30 November	15 000	50	1;2
16-30 November	18 000	35	1;2
16-30 November	18 000	50	1;2
16-30 November	21 000	35	1;2
16-30 November	21 000	50	1;2
16-30 November	21 000	75	1;2
1-15 December	12 000	35	1;2
1-15 December	12 000	50	1;2
1-15 December	15 000	35	1;2
1-15 December	15 000	50	1;2
1-15 December	18 000	35	1;2
1-15 December	18 000	50	1;2
1-15 December	21 000	35	1;2
1-15 December	21 000	50	1;2
1-15 December	21 000	75	1;2

Table A14: Combinations of management practices that provided higher yields for Pioneer 3237 during BN-AN rainfall conditions

Management practices			
Planting date	**Plant population density (plants ha^{-1})**	**Fertiliser application rate (kg ha^{-1} N)**	**Weeding frequency**
1-15 November	9 000	35	1;2
1-15 November	9 000	50	1;3
1-15 November	12 000	35;50	2
1-15 November	12 000	75	3
1-15 November	15 000	35	1;2
1-15 November	15 000	50	2
1-15 November	15 000	75	1;3
1-15 November	18 000	50	1;2
1-15 November	18 000	75	3
1-15 November	21 000	35;50	2
1-15 November	21 000	75	3
16-30 November	9 000	35	1;2
16-30 November	9 000	50	1;3
16-30 November	12 000	35;50	2
16-30 November	12 000	75	3
16-30 November	15 000	35	1;2
16-30 November	15 000	50	2
16-30 November	15 000	75	1;3
16-30 November	18 000	50	1;2
16-30 November	18 000	75	3
16-30 November	21 000	35;50	2
16-30 November	21 000	75	3
1-15 December	9 000	35	1;2
1-15 December	9 000	50	2
1-15 December	12 000	35	1;2
1-15 December	12 000	50;75	2
1-15 December	15 000	35	1;2
1-15 December	15 000	50	2
1-15 December	18 000	35	1;2
1-15 December	18 000	50	2;3
1-15 December	18 000	75	2;3
1-15 December	21 000	35	1;2
1-15 December	21 000	50;75	3

Table A15: Combinations of management practices that provided higher yields for PAN 6479 during BN-NN rainfall conditions

Management practices			
Planting date	**Plant population density (plants ha^{-1})**	**Fertiliser application rate (kg ha^{-1} N)**	**Weeding frequency**
1-15 November	9 000	35	2;3
1-15 November	12 000	35	2;3
1-15 November	15 000	35;50	2
1-15 November	18 000	35	1;3
1-15 November	18 000	50	2
16-30 November	9 000	35	1;2
16-30 November	12 000	35	1;2
16-30 November	15 000	35	2
16-30 November	15 000	50	1;2
16-30 November	18 000	35	1;2
16-30 November	18 000	50	2
16-30 November	21 000	35	3
1-15 December	9 000	35	1;2
1-15 December	12 000	35	1;2
1-15 December	15 000	35	1;2
1-15 December	18 000	35	1;2
1-15 December	18 000	50	2
1-15 December	21 000	35	1;2

Table A16: Combinations of management practices that provided higher yields for Pioneer 3237 during BN-NN rainfall conditions

Management practices			
Planting date	**Plant population density (plants ha^{-1})**	**Fertiliser application rate (kg ha^{-1} N)**	**Weeding frequency**
1-15 November	9 000	35	1;2
1-15 November	9 000	50	3
1-15 November	12 000	35;50	2
1-15 November	12 000	75	3
1-15 November	15 000	35	2
1-15 November	15 000	75	2
1-15 November	15 000	100	3
1-15 November	18 000	50	2
1-15 November	18 000	75	3
1-15 November	21000	35	3
1-15 November	21000	50	2
16-30 November	9 000	35	2
16-30 November	9 000	50	3
16-30 November	12 000	35	3
16-30 November	12 000	50;75	2
16-30 November	15 000	35;50	2
16-30 November	15 000	50	3
16-30 November	18 000	35	3
16-30 November	18 000	50	2
16-30 November	18 000	75	3

Table A17: Combinations of management practices that provided higher yields for PAN 6479 during BN-BN rainfall conditions

Management practices			
Planting date	**Plant population density (plants ha^{-1})**	**Fertiliser application rate (kg ha^{-1} N)**	**Weeding frequency**
1-15 November	9 000	35	1;2
1-15 November	12 000	35	1;2
1-15 November	15 000	35	1;2
1-15 November	18 000	35	1;2
1-15 November	21 000	35	1;2
16-30 November	9 000	35	1;2
16-30 November	12 000	35	1;2
16-30 November	15 000	35	1;2
16-30 November	18 000	35	1;2
16-30 November	21 000	35	1;2
1-15 December	9 000	35	1;2
1-15 December	12 000	35	1;2
1-15 December	15 000	35	1;2
1-15 December	18 000	35	1;2
1-15 December	21 000	35	1;2

Table A18: Combinations of management practices that provided higher yields for Pioneer 3237 during BN-BN rainfall conditions

Management practices			
Planting date	**Plant population density (plants ha^{-1})**	**Fertiliser application rate (kg ha^{-1} N)**	**Weeding frequency**
1-15 November	9 000	35	1;2
1-15 November	12 000	35	1;2
1-15 November	12 000	50	2
1-15 November	15 000	35	1;2
1-15 November	15 000	50	1;2
1-15 November	18 000	35	1;2
1-15 November	18 000	50	1;2
1-15 November	21 000	35	1;2
1-15 November	21 000	50	2
16-30 November	9 000	35	1;2
16-30 November	12 000	35	1;2
16-30 November	15 000	35	1;2
16-30 November	18 000	35	1;2
16-30 November	21 000	35	1;2

Appendix B

Table B1: Reference table for yield expectance, field costs and economic benefit under various sets of management practices during AN-AN rainfall conditions for PAN 6479

Management practices	Probability levels	Yield Expectance (kg ha^{-1})	Field Costs (Rand ha^{-1})	Economic benefit (Rand ha^{-1})
Planted on 1-15 November; 9 000 plants ha^{-1}; 35 kg ha^{-1} N; weeding once	75	1479	1350	603
	50	1358	1350	444
	25	1206	1350	243
Planted on 1-15 November; 9 000 plants ha^{-1}; 35 kg ha^{-1} N; weeding twice	75	1479	1374	579
	50	1417	1374	497
	25	1330	1374	382
Planted on 1-15 November; 12 000 plants ha^{-1}; 35 kg ha^{-1} N; weeding once	75	1807	1400	987
	50	1668	1400	803
	25	1499	1400	581
Planted on 1-15 November; 12 000 plants ha^{-1}; 35 kg ha^{-1} N; weeding twice	75	1922	1424	1114
	50	1788	1424	938
	25	1598	1424	687
Planted on 1-15 November; 15 000 plants ha^{-1}; 35 kg ha^{-1} N; weeding once	75	2043	1449	1250
	50	1963	1449	1144
	25	1654	1449	736
Planted on 1-15 November; 15 000 plants ha^{-1}; 50 kg ha^{-1} N; weeding twice	75	2459	1698	1549
	50	2336	1698	1387
	25	1950	1698	877
Planted on 1-15 November; 18 000 plants ha^{-1}; 35 kg ha^{-1} N; weeding once	75	2354	1499	1610
	50	1981	1499	1118
	25	1664	1499	699
Planted on 1-15 November; 18 000 plants ha^{-1}; 35 kg ha^{-1} N; weeding twice	75	2365	1523	1601
	50	2208	1523	1393
	25	1888	1523	971
Planted on 1-15 November; 18 000 plants ha^{-1}; 50 kg ha^{-1} N; weeding twice	75	2740	1748	1872
	50	2293	1748	1282
	25	2044	1748	952
Planted on 1-15 November; 21 000 plants ha^{-1}; 35 kg ha^{-1} N; weeding once	75	2622	1548	1915
	50	2100	1548	1225
	25	1606	1548	572
Planted on 1-15 November; 21 000 plants ha^{-1}; 35 kg ha^{-1} N; weeding twice	75	2423	1572	1628
	50	2297	1572	1461
	25	2050	1572	1136
Planted on 1-15 November; 21 000 plants ha^{-1}; 50 kg ha^{-1} N; weeding twice	75	3041	1798	2220
	50	2361	1798	1322
	25	2088	1798	960
Planted on 16-30 November; 9 000 plants ha^{-1}; 35 kg ha^{-1} N; weeding once	75	1498	1350	629
	50	1451	1350	567
	25	1188	1350	219
Planted on 16-30 November; 9 000 plants ha^{-1}; 35 kg ha^{-1} N; weeding twice	75	1508	1374	617
	50	1485	1374	588
	25	1445	1374	534
Planted on 16-30 November; 12 000 plants ha^{-1}; 35 kg ha^{-1} N; weeding once	75	1981	1400	1217
	50	1870	1400	1070
	25	1605	1400	720
Planted on 16-30 November; 12 000 plants ha^{-1}; 35 kg ha^{-1} N; weeding twice	75	1977	1424	1188
	50	1936	1424	1133
	25	1883	1424	1063
Planted on 16-30 November; 15 000 plants ha^{-1}; 35 kg ha^{-1} N; weeding once	75	2353	1449	1659
	50	2093	1449	1315
	25	1789	1449	915
Planted on 16-30 November; 15 000 plants ha^{-1}; 50 kg ha^{-1} N; weeding twice	75	2503	1698	1608
	50	2429	1698	1510
	25	2132	1698	1117
Planted on 16-30 November; 18 000 plants ha^{-1}; 35 kg ha^{-1} N; weeding once	75	1352	1499	287
	50	1236	1499	134
	25	1068	1499	-88

Planted on 16-30 November; 18 000 plants ha^{-1}; 35 kg ha^{-1} N; weeding twice	75	2280	1523	1488
	50	2194	1523	1375
	25	2112	1523	1267
Planted on 16-30 November; 18 000 plants ha^{-1}; 50 kg ha^{-1} N; weeding twice	75	2871	1748	2045
	50	2690	1748	1805
	25	2498	1748	1552
Planted on 16-30 November; 21 000 plants ha^{-1}; 35 kg ha^{-1} N; weeding once	75	2474	1548	1720
	50	2221	1548	1386
	25	1949	1548	1027
Planted on 16-30 November; 21 000 plants ha^{-1}; 35 kg ha^{-1} N; weeding twice	75	2378	1572	1569
	50	2276	1572	1435
	25	2148	1572	1265
Planted on 16-30 November; 21 000 plants ha^{-1}; 50 kg ha^{-1} N; weeding twice	75	3032	1798	2208
	50	2854	1798	1972
	25	2502	1798	1508
Planted on 1-15 December; 9 000 plants ha^{-1}; 35 kg ha^{-1} N; weeding once	75	1296	1350	362
	50	976	1350	-62
	25	597	1350	-562
Planted on 1-15 December; 9 000 plants ha^{-1}; 35 kg ha^{-1} N; weeding twice	75	1420	1374	502
	50	1314	1374	361
	25	1130	1374	119
Planted on 1-15 December; 12 000 plants ha^{-1}; 35 kg ha^{-1} N; weeding once	75	1589	1400	700
	50	1093	1400	44
	25	659	1400	-530
Planted on 1-15 December; 12 000 plants ha^{-1}; 35 kg ha^{-1} N; weeding twice	75	1693	1424	812
	50	1532	1424	600
	25	1270	1424	254
Planted on 1-15 December; 15 000 plants ha^{-1}; 35 kg ha^{-1} N; weeding once	75	1723	1449	827
	50	1195	1449	129
	25	756	1449	-451
Planted on 1-15 December; 15 000 plants ha^{-1}; 50 kg ha^{-1} N; weeding twice	75	2161	1698	1157
	50	1914	1698	829
	25	1642	1698	470
Planted on 1-15 December; 18 000 plants ha^{-1}; 35 kg ha^{-1} N; weeding once	75	1937	1499	1060
	50	1269	1499	177
	25	865	1499	-357
Planted on 1-15 December; 18 000 plants ha^{-1}; 35 kg ha^{-1} N; weeding twice	75	1936	1523	1034
	50	1842	1523	911
	25	1330	1523	234
Planted on 1-15 December; 18 000 plants ha^{-1}; 50 kg ha^{-1} N; weeding twice	75	2339	1748	1341
	50	2208	1748	1168
	25	1767	1748	586
Planted on 1-15 December; 21 000 plants ha^{-1}; 35 kg ha^{-1} N; weeding once	75	2055	1548	1166
	50	1346	1548	229
	25	831	1548	-450
Planted on 1-15 December; 21 000 plants ha^{-1}; 35 kg ha^{-1} N; weeding twice	75	1997	1572	1065
	50	1903	1572	942
	25	1344	1572	203
Planted on 1-15 December; 21 000 plants ha^{-1}; 50 kg ha^{-1} N; weeding twice	75	2504	1798	1511
	50	2306	1798	1248
	25	1797	1798	576

Table B2: Reference table for yield expectance, field costs and economic benefit under various sets of management practices during AN-AN rainfall conditions for Pioneer 3237

Management practices (For Pioneer 3237 cultivar)	Probability levels	Yield Expectance (kg ha^{-1})	Field Costs (Rand ha^{-1})	Economic benefit (Rand ha^{-1})
Planted on 1-15 November; 9 000 plants ha^{-1}; 35 kg ha^{-1} N; weeding twice	75	2461	1445	1806
	50	2106	1445	1336
	25	1926	1445	1099
Planted on 1-15 November; 9 000 plants ha^{-1}; 50 kg ha^{-1} N; weeding twice	75	2777	1670	1998
	50	2533	1670	1676
	25	757	1670	-671
Planted on 1-15 November; 9 000 plants ha^{-1}; 75 kg ha^{-1} N; weeding twice	75	3368	2045	2403
	50	2903	2045	1789
	25	2663	2045	1473
Planted on 1-15 November; 12 000 plants ha^{-1}; 35 kg ha^{-1} N; weeding twice	75	2536	1518	1832
	50	2223	1518	1418
	25	2061	1518	1205

Planted on 1-15 November; 12 000 plants ha^{-1}; 50 kg ha^{-1} N; weeding twice	75	3194	1743	2476
	50	2872	1743	2051
	25	2644	1743	1750
Planted on 1-15 November; 12 000 plants ha^{-1}; 75 kg ha^{-1} N; weeding twice	75	4064	2118	3250
	50	3484	2118	2485
	25	3183	2118	2086
Planted on 1-15 November; 15 000 plants ha^{-1}; 50 kg ha^{-1} N; weeding twice	75	3316	1816	2564
	50	2876	1816	1983
	25	2460	1816	1433
Planted on 1-15 November; 15 000 plants ha^{-1}; 75 kg ha^{-1} N; weeding twice	75	4342	2191	3544
	50	3825	2191	2861
	25	2938	2191	1689
Planted on 1-15 November; 18 000 plants ha^{-1}; 50 kg ha^{-1} N; weeding twice	75	3377	1890	2571
	50	2946	1890	2002
	25	2554	1890	1484
Planted on 1-15 November; 18 000 plants ha^{-1}; 75 kg ha^{-1} N; weeding twice	75	4413	2265	3564
	50	4135	2265	3197
	25	2974	2265	1665
Planted on 1-15 November; 21 000 plants ha^{-1}; 75 kg ha^{-1} N; weeding twice	75	4462	2338	3557
	50	4232	2338	3253
	25	3795	2338	2675
Planted on 16-30 November; 9 000 plants ha^{-1}; 50 kg ha^{-1} N; weeding once	75	2774	1646	2018
	50	2160	1646	1207
	25	704	1646	-717
Planted on 16-30 November; 9 000 plants ha^{-1}; 75 kg ha^{-1} N; weeding twice	75	3171	2045	2144
	50	2859	2045	1731
	25	1622	2045	98
Planted on 16-30 November; 12 000 plants ha^{-1}; 75 kg ha^{-1} N; weeding twice	75	3874	2118	2999
	50	3294	2118	2233
	25	1836	2118	307
Planted on 16-30 November; 15 000 plants ha^{-1}; 50 kg ha^{-1} N; weeding once	75	3252	1792	2504
	50	2689	1792	1759
	25	935	1792	-557
Planted on 16-30 November; 15 000 plants ha^{-1}; 75 kg ha^{-1} N; weeding twice	75	4235	2191	3403
	50	3498	2191	2430
	25	1991	2191	439
Planted on 16-30 November; 18 000 plants ha^{-1}; 35 kg ha^{-1} N; weeding once	75	2569	1640	1753
	50	2209	1640	1278
	25	1542	1640	397
Planted on 16-30 November; 18 000 plants ha^{-1}; 50 kg ha^{-1} N; weeding once	75	3336	1865	2541
	50	2804	1865	1838
	25	1091	1865	-425
Planted on 16-30 November; 18 000 plants ha^{-1}; 75 kg ha^{-1} N; weeding twice	75	4340	2265	3469
	50	3570	2265	2452
	25	2153	2265	579
Planted on 16-30 November; 21 000 plants ha^{-1}; 35 kg ha^{-1} N; weeding once	75	2584	1713	1701
	50	2296	1713	1320
	25	1600	1713	400
Planted on 16-30 November; 21 000 plants ha^{-1}; 50 kg ha^{-1} N; weeding once	75	3395	1939	2546
	50	2872	1939	1856
	25	1266	1939	-266
Planted on 16-30 November; 21 000 plants ha^{-1}; 75 kg ha^{-1} N; weeding twice	75	4437	2338	3523
	50	3638	2338	2468
	25	2218	2338	592

Table B3: Reference table for yield expectance, field costs and economic benefit under various sets of management practices during AN-NN rainfall conditions for PAN 6479

Management practices (For PAN 6479 cultivar)	Probability levels	Yield Expectance (kg ha^{-1})	Field Costs (Rand ha^{-1})	Economic benefit (Rand ha^{-1})
Planted on 1-15 November; 9 000 plants ha^{-1}; 35 kg ha^{-1} N; weeding once	75	1199	1350	234
	50	1043	1350	28
	25	666	1350	-470
Planted on 1-15 November; 9 000 plants ha^{-1}; 35 kg ha^{-1} N; weeding twice	75	1436	1374	522
	50	1368	1374	432
	25	1296	1374	337
Planted on 1-15 November; 12 000 plants ha^{-1}; 35 kg ha^{-1} N; weeding once	75	1420	1400	476
	50	1204	1400	191
	25	653	1400	-537

Planted on 1-15 November; 12 000 plants ha^{-1}; 35 kg ha^{-1} N; weeding twice	75	1845	1424	1013
	50	1728	1424	859
	25	1572	1424	652
Planted on 1-15 November; 15 000 plants ha^{-1}; 35 kg ha^{-1} N; weeding once	75	1550	1449	598
	50	1225	1449	169
	25	632	1449	-615
Planted on 1-15 November; 15 000 plants ha^{-1}; 35 kg ha^{-1} N; weeding twice	75	2071	1473	1262
	50	1785	1473	884
	25	1634	1473	685
Planted on 1-15 November; 15 000 plants ha^{-1}; 50 kg ha^{-1} N; weeding twice	75	2275	1698	1307
	50	2091	1698	1064
	25	1629	1698	454
Planted on 1-15 November; 18 000 plants ha^{-1}; 35 kg ha^{-1} N; weeding once	75	1675	1499	714
	50	1357	1499	294
	25	594	1499	-714
Planted on 1-15 November; 18 000 plants ha^{-1}; 35 kg ha^{-1} N; weeding twice	75	2191	1523	1371
	50	1847	1523	917
	25	1705	1523	729
Planted on 1-15 November; 18 000 plants ha^{-1}; 50 kg ha^{-1} N; weeding twice	75	2256	1748	1233
	50	1929	1748	801
	25	1647	1748	428
Planted on 1-15 November; 21 000 plants ha^{-1}; 35 kg ha^{-1} N; weeding once	75	1796	1548	825
	50	1411	1548	315
	25	545	1548	-828
Planted on 1-15 November; 21 000 plants ha^{-1}; 35 kg ha^{-1} N; weeding twice	75	2323	1572	1496
	50	1814	1572	823
	25	1775	1572	773
Planted on 1-15 November; 21 000 plants ha^{-1}; 50 kg ha^{-1} N; weeding twice	75	2581	1798	1612
	50	1945	1798	771
	25	1642	1798	372
Planted on 16-30 November; 9 000 plants ha^{-1}; 35 kg ha^{-1} N; weeding once	75	1299	1350	366
	50	1098	1350	100
	25	972	1350	-66
Planted on 16-30 November; 9 000 plants ha^{-1}; 35 kg ha^{-1} N; weeding twice	75	1471	1374	568
	50	1411	1374	489
	25	1339	1374	395
Planted on 16-30 November; 12 000 plants ha^{-1}; 35 kg ha^{-1} N; weeding once	75	1512	1400	598
	50	1308	1400	328
	25	1034	1400	-34
Planted on 16-30 November; 12 000 plants ha^{-1}; 35 kg ha^{-1} N; weeding twice	75	1936	1424	1134
	50	1828	1424	991
	25	1764	1424	906
Planted on 16-30 November; 15 000 plants ha^{-1}; 35 kg ha^{-1} N; weeding once	75	1625	1449	697
	50	1396	1449	395
	25	1078	1449	-25
Planted on 16-30 November; 15 000 plants ha^{-1}; 35 kg ha^{-1} N; weeding twice	75	2217	1473	1455
	50	2064	1473	1254
	25	1847	1473	967
Planted on 16-30 November; 15 000 plants ha^{-1}; 50 kg ha^{-1} N; weeding twice	75	2256	1698	1282
	50	2081	1698	1051
	25	1840	1698	731
Planted on 16-30 November; 18 000 plants ha^{-1}; 35 kg ha^{-1} N; weeding once	75	1702	1499	750
	50	1423	1499	380
	25	1048	1499	-115
Planted on 16-30 November; 18 000 plants ha^{-1}; 35 kg ha^{-1} N; weeding twice	75	2335	1523	1561
	50	2199	1523	1382
	25	1905	1523	994
Planted on 16-30 November; 18 000 plants ha^{-1}; 50 kg ha^{-1} N; weeding twice	75	2491	1748	1543
	50	2310	1748	1304
	25	1845	1748	689
Planted on 16-30 November; 21 000 plants ha^{-1}; 35 kg ha^{-1} N; weeding once	75	1821	1548	857
	50	1433	1548	345
	25	976	1548	-259
Planted on 16-30 November; 21 000 plants ha^{-1}; 35 kg ha^{-1} N; weeding twice	75	2429	1572	1636
	50	2228	1572	1371
	25	1948	1572	1001
Planted on 16-30 November; 21 000 plants ha^{-1}; 50 kg ha^{-1} N; weeding twice	75	2698	1798	1766
	50	2437	1798	1421
	25	1899	1798	711

Planted on 1-15 December; 9 000 plants ha^{-1}; 35 kg ha^{-1} N; weeding once	75	1321	1350	395
	50	825	1350	-260
	25	216	1350	-1065
Planted on 1-15 December; 9 000 plants ha^{-1}; 35 kg ha^{-1} N; weeding twice	75	1481	1374	583
	50	1443	1374	531
	25	263	1374	-1027
Planted on 1-15 December; 12 000 plants ha^{-1}; 35 kg ha^{-1} N; weeding once	75	1688	1400	831
	50	939	1400	-159
	25	263	1400	-1052
Planted on 1-15 December; 12 000 plants ha^{-1}; 35 kg ha^{-1} N; weeding twice	75	1911	1424	1101
	50	1735	1424	868
	25	341	1424	-973
Planted on 1-15 December; 15 000 plants ha^{-1}; 35 kg ha^{-1} N; weeding once	75	1668	1449	753
	50	1004	1449	-124
	25	283	1449	-1076
Planted on 1-15 December; 15 000 plants ha^{-1}; 35 kg ha^{-1} N; weeding twice	75	2137	1473	1350
	50	1892	1473	1025
	25	407	1473	-936
Planted on 1-15 December; 15 000 plants ha^{-1}; 50 kg ha^{-1} N; weeding twice	75	1986	1698	924
	50	1461	1698	231
	25	277	1698	-1333
Planted on 1-15 December; 18 000 plants ha^{-1}; 35 kg ha^{-1} N; weeding thrice	75	2247	1547	1421
	50	1884	1547	942
	25	462	1547	-936
Planted on 1-15 December; 18 000 plants ha^{-1}; 50 kg ha^{-1} N; weeding twice	75	2145	1523	1311
	50	1593	1523	581
	25	206	1523	-1251
Planted on 1-15 December; 21 000 plants ha^{-1}; 35 kg ha^{-1} N; weeding thrice	75	2332	1597	1484
	50	1966	1597	1001
	25	504	1597	-931
Planted on 1-15 December; 21 000 plants ha^{-1}; 50 kg ha^{-1} N; weeding twice	75	2503	1798	1509
	50	1972	1798	808
	75	514	1798	-1119

Table B4: Reference table for yield expectance, field costs and economic benefit under various sets of management practices during AN-NN rainfall conditions for Pioneer 3237

Management practices (For Pioneer 3237 cultivar)	Probability levels	Yield Expectance (kg ha^{-1})	Field Costs (Rand ha^{-1})	Economic benefit (Rand ha^{-1})
Planted on 1-15 November; 9 000 plants ha^{-1}; 35 kg ha^{-1} N; weeding once	75	1921	1421	1116
	50	1244	1421	223
	25	854	1421	-292
Planted on 1-15 November; 9 000 plants ha^{-1}; 35 kg ha^{-1} N; weeding twice	75	2404	1445	1730
	50	2210	1445	1475
	25	2014	1445	1215
Planted on 1-15 November; 9 000 plants ha^{-1}; 50 kg ha^{-1} N; weeding once	75	1823	1646	763
	50	1385	1646	183
	25	1052	1646	-256
Planted on 1-15 November; 9 000 plants ha^{-1}; 50 kg ha^{-1} N; weeding twice	75	2833	1670	2072
	50	2715	1670	1916
	25	2119	1670	1129
Planted on 1-15 November; 9 000 plants ha^{-1}; 50 kg ha^{-1} N; weeding thrice	75	3091	1694	2390
	50	2991	1694	2256
	25	2780	1694	1979
Planted on 1-15 November; 9 000 plants ha^{-1}; 75 kg ha^{-1} N; weeding twice	75	3157	2045	2125
	50	2902	2045	1789
	25	2385	2045	1105
Planted on 1-15 November; 9 000 plants ha^{-1}; 75 kg ha^{-1} N; weeding thrice	75	3333	2069	2334
	50	3188	2069	2143
	25	3027	2069	1930
Planted on 1-15 November; 12 000 plants ha^{-1}; 50 kg ha^{-1} N; weeding twice	75	3033	1743	2264
	50	2820	1743	1982
	25	2638	1743	1742
Planted on 1-15 November; 12 000 plants ha^{-1}; 50 kg ha^{-1} N; weeding thrice	75	3101	1767	2329
	50	2974	1767	2161
	25	2784	1767	1910
Planted on 1-15 November; 12 000 plants ha^{-1}; 75 kg ha^{-1} N; weeding twice	75	3932	2118	3076
	50	3215	2118	2129
	25	2715	2118	1469

Planted on 1-15 November; 12 000 plants ha^{-1}; 75 kg ha^{-1} N; weeding thrice	75	4031	2142	3182
	50	3686	2142	2726
	25	3210	2142	2097
Planted on 1-15 November; 21 000 plants ha^{-1}; 75 kg ha^{-1} N; weeding thrice	75	4188	2362	3171
	50	3678	2362	2497
	25	3277	2362	1967
Planted on 16-30 November; 9 000 plants ha^{-1}; 35 kg ha^{-1} N; weeding once	75	1616	1421	713
	50	1066	1421	-12
	25	688	1421	-512
Planted on 16-30 November; 9 000 plants ha^{-1}; 35 kg ha^{-1} N; weeding twice	75	2316	1445	1614
	50	2048	1445	1260
	25	1905	1445	1071
Planted on 16-30 November; 9 000 plants ha^{-1}; 50 kg ha^{-1} N; weeding once	75	1874	1646	830
	50	1240	1646	-8
	25	842	1646	-534
Planted on 16-30 November; 9 000 plants ha^{-1}; 50 kg ha^{-1} N; weeding twice	75	2526	1670	1667
	50	2138	1670	1154
	25	1396	1670	174
Planted on 16-30 November; 9 000 plants ha^{-1}; 50 kg ha^{-1} N; weeding thrice	75	2853	1694	2075
	50	2474	1694	1574
	25	2100	1694	1080
Planted on 16-30 November; 9 000 plants ha^{-1}; 75 kg ha^{-1} N; weeding twice	75	2775	2045	1621
	50	2105	2045	735
	25	1800	2045	333
Planted on 16-30 November; 9 000 plants ha^{-1}; 75 kg ha^{-1} N; weeding thrice	75	3061	2069	1975
	50	2777	2069	1599
	25	2174	2069	803
Planted on 16-30 November; 12 000 plants ha^{-1}; 35 kg ha^{-1} N; weeding twice	75	2370	1518	1612
	50	2182	1518	1365
	25	2079	1518	1228
Planted on 16-30 November; 12 000 plants ha^{-1}; 50 kg ha^{-1} N; weeding twice	75	2777	1743	1925
	50	2622	1743	1720
	25	2473	1743	1523
Planted on 16-30 November; 12 000 plants ha^{-1}; 50 kg ha^{-1} N; weeding thrice	75	3045	1767	2254
	50	2882	1767	2040
	25	2364	1767	1355
Planted on 16-30 November; 12 000 plants ha^{-1}; 75 kg ha^{-1} N; weeding twice	75	3355	2118	2314
	50	2557	2118	1260
	25	1949	2118	456
Planted on 16-30 November; 12 000 plants ha^{-1}; 75 kg ha^{-1} N; weeding thrice	75	3542	2142	2537
	50	3106	2142	1961
	25	2786	2142	1538
Planted on 16-30 November; 15 000 plants ha^{-1}; 35 kg ha^{-1} N; weeding twice	75	2490	1591	1698
	50	2262	1591	1397
	25	2159	1591	1260
Planted on 16-30 November; 15 000 plants ha^{-1}; 50 kg ha^{-1} N; weeding twice	75	2827	1816	1918
	50	2733	1816	1793
	25	2583	1816	1596
Planted on 16-30 November; 15 000 plants ha^{-1}; 50 kg ha^{-1} N; weeding thrice	75	3149	1840	2319
	50	2898	1840	1988
	25	2653	1840	1664
Planted on 16-30 November; 15 000 plants ha^{-1}; 75 kg ha^{-1} N; weeding twice	75	3556	2191	2506
	50	2609	2191	1255
	25	2103	2191	586
Planted on 16-30 November; 15 000 plants ha^{-1}; 75 kg ha^{-1} N; weeding thrice	75	3791	2216	2792
	50	3382	2216	2252
	25	2909	2216	1627
Planted on 1-15 December; 9 000 plants ha^{-1}; 35 kg ha^{-1} N; weeding once	75	1195	1421	157
	50	697	1421	-500
	25	0	1421	-1421
Planted on 1-15 December; 9 000 plants ha^{-1}; 35 kg ha^{-1} N; weeding twice	75	1960	1445	1145
	50	1181	1445	116
	25	0	1445	-1445
Planted on 1-15 December; 9 000 plants ha^{-1}; 50 kg ha^{-1} N; weeding once	75	1450	1646	269
	50	686	1646	-740
	25	0	1646	-1646
Planted on 1-15 December; 9 000 plants ha^{-1}; 50 kg ha^{-1} N; weeding twice	75	1998	1670	969
	50	1181	1670	-109
	25	0	1670	-1670

Planted on 1-15 December; 9 000 plants ha^{-1}; 50 kg ha^{-1} N; weeding thrice	75	2132	1694	1122
	50	1412	1694	171
	25	0	1694	-1694
Planted on 1-15 December; 9 000 plants ha^{-1}; 75 kg ha^{-1} N; weeding twice	75	1996	2045	591
	50	1093	2045	-602
	25	0	2045	-2045
Planted on 1-15 December; 9 000 plants ha^{-1}; 75 kg ha^{-1} N; weeding thrice	75	1998	2069	570
	50	1371	2069	-258
	25	0	2069	-2069
Planted on 1-15 December; 12 000 plants ha^{-1}; 35 kg ha^{-1} N; weeding twice	75	2071	1518	1217
	50	1304	1518	204
	25	0	1518	-1518
Planted on 1-15 December; 12 000 plants ha^{-1}; 50 kg ha^{-1} N; weeding twice	75	2577	1743	1661
	50	1507	1743	248
	25	0	1743	-1743
Planted on 1-15 December; 12 000 plants ha^{-1}; 50 kg ha^{-1} N; weeding thrice	75	2504	1767	1541
	50	1611	1767	360
	25	0	1767	-1767
Planted on 1-15 December; 12 000 plants ha^{-1}; 75 kg ha^{-1} N; weeding twice	75	2564	2118	1268
	50	1345	2118	-342
	25	0	2118	-2118
Planted on 1-15 December; 12 000 plants ha^{-1}; 75 kg ha^{-1} N; weeding thrice	75	2769	2142	1516
	50	1636	2142	18
	25	0	2142	-2142
Planted on 1-15 December; 15 000 plants ha^{-1}; 35 kg ha^{-1} N; weeding twice	75	2130	1591	1222
	50	1396	1591	253
	25	0	1591	-1591
Planted on 1-15 December; 15 000 plants ha^{-1}; 50 kg ha^{-1} N; weeding twice	75	2634	1816	1664
	50	1580	1816	271
	25	0	1816	-1816
Planted on 1-15 December; 15 000 plants ha^{-1}; 50 kg ha^{-1} N; weeding thrice	75	2633	1840	1637
	50	1692	1840	395
	25	0	1840	-1840
Planted on 1-15 December; 15 000 plants ha^{-1}; 75 kg ha^{-1} N; weeding twice	75	2758	2191	1452
	50	1537	2191	-161
	25	0	2191	-2191
Planted on 1-15 December; 15 000 plants ha^{-1}; 75 kg ha^{-1} N; weeding thrice	75	3026	2216	1782
	50	1781	2216	137
	25	0	2216	-2216

Table B5: Reference table for yield expectance, field costs and economic benefit under various sets of management practices during AN-BN rainfall conditions for PAN 6479

Management practices (For PAN 6479 cultivar)	**Probability levels**	**Yield Expectance (kg ha^{-1})**	**Field Costs (Rand ha^{-1})**	**Economic benefit (Rand ha^{-1})**
Planted on 1-15 November; 9 000 plants ha^{-1}; 35 kg ha^{-1} N; weeding once	75	1085	1350	83
	50	907	1350	-151
	25	410	1350	-808
Planted on 1-15 November; 9 000 plants ha^{-1}; 35 kg ha^{-1} N; weeding twice	75	1324	1374	375
	50	1151	1374	146
	25	979	1374	-81
Planted on 1-15 November; 12 000 plants ha^{-1}; 35 kg ha^{-1} N; weeding once	75	1150	1400	119
	50	913	1400	-194
	25	439	1400	-820
Planted on 1-15 November; 12 000 plants ha^{-1}; 35 kg ha^{-1} N; weeding twice	75	1662	1424	771
	50	1446	1424	487
	25	1005	1424	-96
Planted on 1-15 November; 15 000 plants ha^{-1}; 35 kg ha^{-1} N; weeding once	75	1246	1449	196
	50	897	1449	-265
	25	436	1449	-874
Planted on 1-15 November; 15 000 plants ha^{-1}; 35 kg ha^{-1} N; weeding twice	75	1774	1473	870
	50	1510	1473	521
	25	990	1473	-166
Planted on 1-15 November; 18 000 plants ha^{-1}; 35 kg ha^{-1} N; weeding once	75	1487	1499	466
	50	959	1499	-231
	25	532	1499	-796
Planted on 1-15 November; 18 000 plants ha^{-1}; 35 kg ha^{-1} N; weeding twice	75	1826	1523	890
	50	1527	1523	494
	25	940	1523	-282

Planted on 16-30 November; 9 000 plants ha^{-1}; 35 kg ha^{-1} N; weeding once	75	1126	1350	138
	50	1057	1350	47
	25	892	1350	-171
Planted on 16-30 November; 9 000 plants ha^{-1}; 35 kg ha^{-1} N; weeding twice	75	1389	1374	461
	50	1314	1374	362
	25	941	1374	-131
Planted on 16-30 November; 12 000 plants ha^{-1}; 35 kg ha^{-1} N; weeding once	75	1382	1400	426
	50	1116	1400	75
	25	853	1400	-273
Planted on 16-30 November; 12 000 plants ha^{-1}; 35 kg ha^{-1} N; weeding twice	75	1820	1424	980
	50	1617	1424	712
	25	944	1424	-177
Planted on 16-30 November; 15 000 plants ha^{-1}; 35 kg ha^{-1} N; weeding once	75	1394	1449	392
	50	1173	1449	100
	25	755	1449	-452
Planted on 16-30 November; 15 000 plants ha^{-1}; 35 kg ha^{-1} N; weeding twice	75	2064	1473	1253
	50	1660	1473	719
	25	913	1473	-268
Planted on 16-30 November; 18 000 plants ha^{-1}; 35 kg ha^{-1} N; weeding once	75	1426	1499	384
	50	1254	1499	158
	25	677	1499	-604
Planted on 16-30 November; 18 000 plants ha^{-1}; 35 kg ha^{-1} N; weeding thrice	75	2218	1547	1382
	50	1705	1547	706
	25	907	1547	-349
Planted on 16-30 November; 21 000 plants ha^{-1}; 35 kg ha^{-1} N; weeding thrice	75	2278	1597	1412
	50	1773	1597	746
	25	1061	1597	-194
Planted on 1-15 December; 9 000 plants ha^{-1}; 35 kg ha^{-1} N; weeding once	75	1265	1350	321
	50	914	1350	-143
	25	227	1350	-1051
Planted on 1-15 December; 9 000 plants ha^{-1}; 35 kg ha^{-1} N; weeding twice	75	1427	1374	511
	50	1337	1374	392
	25	319	1374	-954
Planted on 1-15 December; 12 000 plants ha^{-1}; 35 kg ha^{-1} N; weeding once	75	1460	1400	529
	50	920	1400	-184
	25	252	1400	-1067
Planted on 1-15 December; 12 000 plants ha^{-1}; 35 kg ha^{-1} N; weeding twice	75	1803	1424	958
	50	1407	1424	435
	25	415	1424	-876

Table B6: Reference table for yield expectance, field costs and economic benefit under various sets of management practices during AN-BN rainfall conditions for Pioneer 3237

Management practices (For Pioneer 3237 cultivar)	**Probability levels**	**Yield Expectance (kg ha^{-1})**	**Field Costs (Rand ha^{-1})**	**Economic benefit (Rand ha^{-1})**
Planted on 1-15 November; 9 000 plants ha^{-1}; 35 kg ha^{-1} N; weeding twice	75	2269	1445	1553
	50	1862	1445	1014
	25	1537	1445	586
Planted on 1-15 November; 9 000 plants ha^{-1}; 35 kg ha^{-1} N; weeding thrice	75	2198	1469	1434
	50	2095	1469	1298
	25	1775	1469	875
Planted on 1-15 November; 9 000 plants ha^{-1}; 50 kg ha^{-1} N; weeding thrice	75	2732	1694	1915
	50	2352	1694	1412
	25	1666	1694	506
Planted on 1-15 November; 9 000 plants ha^{-1}; 75 kg ha^{-1} N; weeding thrice	75	3207	2069	2166
	50	2413	2069	1118
	25	1733	2069	221
Planted on 16-30 November; 9 000 plants ha^{-1}; 35 kg ha^{-1} N; weeding thrice	75	1394	1469	372
	50	1322	1469	278
	25	981	1469	-173
Planted on 16-30 November; 9 000 plants ha^{-1}; 50 kg ha^{-1} N; weeding thrice	75	2447	1694	1539
	50	1957	1694	891
	25	1537	1694	337
Planted on 16-30 November; 9 000 plants ha^{-1}; 75 kg ha^{-1} N; weeding thrice	75	2533	2069	1276
	50	1910	2069	453
	25	1568	2069	1
Planted on 16-30 November; 12 000 plants ha^{-1}; 35 kg ha^{-1} N; weeding once	75	1526	1494	522
	50	1223	1494	121
	25	608	1494	-690

Planted on 16-30 November; 12 000 plants ha^{-1}; 35 kg ha^{-1} N; weeding twice	75	2221	1518	1415
	50	1734	1518	772
	25	1483	1518	441
Planted on 16-30 November; 12 000 plants ha^{-1}; 50 kg ha^{-1} N; weeding twice	75	2545	1743	1619
	50	2036	1743	947
	25	1493	1743	229
Planted on 16-30 November; 12 000 plants ha^{-1}; 75 kg ha^{-1} N; weeding thrice	75	2712	2142	1440
	50	2011	2142	514
	25	1512	2142	-145

Table B7: Reference table for yield expectance, field costs and economic benefit under various sets of management practices during NN-AN rainfall conditions for PAN 6479

Management practices (For PAN 6479 cultivar)	**Probability levels**	**Yield Expectance (kg ha^{-1})**	**Field Costs (Rand ha^{-1})**	**Economic benefit (Rand ha^{-1})**
Planted on 1-15 November; 9 000 plants ha^{-1}; 35 kg ha^{-1} N; one times of weeding control	75	1457	1350	574
	50	1338	1350	418
	25	1171	1350	197
Planted on 1-15 November; 9 000 plants ha^{-1}; 35 kg ha^{-1} N; weeding twice	75	1507	1374	617
	50	1484	1374	587
	25	1377	1374	445
Planted on 1-15 November; 12 000 plants ha^{-1}; 35 kg ha^{-1} N; weeding once	75	1799	1400	977
	50	1631	1400	755
	25	1274	1400	283
Planted on 1-15 November; 12 000 plants ha^{-1}; 35 kg ha^{-1} N; weeding twice	75	1975	1424	1185
	50	1830	1424	993
	25	1697	1424	818
Planted on 1-15 November; 15 000 plants ha^{-1}; 35 kg ha^{-1} N; weeding once	75	1982	1449	1168
	50	1821	1449	956
	25	1393	1449	390
Planted on 1-15 November; 15 000 plants ha^{-1}; 35 kg ha^{-1} N; weeding twice	75	2225	1473	1465
	50	2063	1473	1252
	25	1876	1473	1004
Planted on 1-15 November; 15 000 plants ha^{-1}; 50 kg ha^{-1} N; weeding once	75	2209	1674	1243
	50	2011	1674	982
	25	1353	1674	113
Planted on 1-15 November; 15 000 plants ha^{-1}; 50 kg ha^{-1} N; weeding twice	75	2455	1698	1545
	50	2314	1698	1358
	25	2217	1698	1230
Planted on 1-15 November; 18 000 plants ha^{-1}; 35 kg ha^{-1} N; weeding once	75	2182	1499	1384
	50	2053	1499	1213
	25	1501	1499	484
Planted on 1-15 November; 18 000 plants ha^{-1}; 35 kg ha^{-1} N; weeding twice	75	2352	1523	1585
	50	2271	1523	1477
	25	1999	1523	1117
Planted on 1-15 November; 18 000 plants ha^{-1}; 50 kg ha^{-1} N; weeding once	75	2295	1724	1307
	50	1711	1724	536
	25	1189	1724	-153
Planted on 1-15 November; 18 000 plants ha^{-1}; 50 kg ha^{-1} N; weeding twice	75	2595	1748	1680
	50	2420	1748	1449
	25	2300	1748	1290
Planted on 1-15 November; 21 000 plants ha^{-1}; 35 kg ha^{-1} N; weeding once	75	2518	1548	1778
	50	2184	1548	1337
	25	1609	1548	577
Planted on 1-15 November; 21 000 plants ha^{-1}; 35 kg ha^{-1} N; weeding twice	75	2528	1572	1766
	50	2402	1572	1600
	25	2073	1572	1166
Planted on 1-15 November; 21 000 plants ha^{-1}; 50 kg ha^{-1} N; weeding once	75	2582	1773	1637
	50	2299	1773	1264
	25	1308	1773	-46
Planted on 1-15 November; 21 000 plants ha^{-1}; 50 kg ha^{-1} N; weeding twice	75	2889	1798	2019
	50	2516	1798	1526
	25	2390	1798	1359
Planted on 16-30 November; 9 000 plants ha^{-1}; 35 kg ha^{-1} N; weeding once	75	1511	1350	645
	50	1309	1350	378
	25	1123	1350	133
Planted on 16-30 November; 9 000 plants ha^{-1}; 35 kg ha^{-1} N; weeding twice	75	1531	1374	649
	50	1453	1374	545
	25	1210	1374	225

Planted on 16-30 November; 12 000 plants ha^{-1}; 35 kg ha^{-1} N; weeding once	75	1890	1400	1097
	50	1614	1400	732
	25	1212	1400	202
Planted on 16-30 November; 12 000 plants ha^{-1}; 35 kg ha^{-1} N; weeding twice	75	2037	1424	1267
	50	1893	1424	1076
	25	1488	1424	542
Planted on 16-30 November; 12 000 plants ha^{-1}; 50 kg ha^{-1} N; weeding once	75	1927	1625	920
	50	1711	1625	636
	25	1286	1625	74
Planted on 16-30 November; 15 000 plants ha^{-1}; 35 kg ha^{-1} N; weeding once	75	2188	1450	1441
	50	1836	1450	976
	25	1217	1450	159
Planted on 16-30 November; 15 000 plants ha^{-1}; 35 kg ha^{-1} N; weeding twice	75	2379	1474	1669
	50	2227	1474	1469
	25	1684	1474	750
Planted on 16-30 November; 15 000 plants ha^{-1}; 50 kg ha^{-1} N; weeding once	75	2356	1674	1438
	50	1961	1674	917
	25	1338	1674	94
Planted on 16-30 November; 15 000 plants ha^{-1}; 50 kg ha^{-1} N; weeding twice	75	2546	1698	1664
	50	2300	1698	1340
	25	1854	1698	750
Planted on 16-30 November; 18 000 plants ha^{-1}; 35 kg ha^{-1} N; weeding once	75	2412	1499	1688
	50	1986	1499	1125
	25	1190	1499	73
Planted on 16-30 November; 18 000 plants ha^{-1}; 35 kg ha^{-1} N; weeding twice	75	2579	1523	1883
	50	2231	1523	1424
	25	1798	1523	852
Planted on 16-30 November; 18 000 plants ha^{-1}; 50 kg ha^{-1} N; weeding once	75	2648	1724	1774
	50	2147	1724	1112
	25	1448	1724	189
Planted on 16-30 November; 18 000 plants ha^{-1}; 50 kg ha^{-1} N; weeding twice	75	2911	1748	2097
	50	2671	1748	1780
	25	2114	1748	1044
Planted on 16-30 November; 21 000 plants ha^{-1}; 35 kg ha^{-1} N; weeding once	75	2509	1548	1765
	50	2155	1548	1298
	25	1170	1548	-3
Planted on 16-30 November; 21 000 plants ha^{-1}; 35 kg ha^{-1} N; weeding twice	75	2690	1572	1981
	50	2322	1572	1494
	25	1884	1572	916
Planted on 16-30 November; 21 000 plants ha^{-1}; 50 kg ha^{-1} N; weeding once	75	2844	1773	1984
	50	2308	1773	1275
	25	1505	1773	214
Planted on 16-30 November; 21 000 plants ha^{-1}; 50 kg ha^{-1} N; weeding twice	75	3100	1798	2298
	50	2940	1798	2086
	25	2258	1798	1185
Planted on 1-15 December; 9 000 plants ha^{-1}; 35 kg ha^{-1} N; weeding once	75	1481	1350	606
	50	1266	1350	322
	25	468	1350	-732
Planted on 1-15 December; 9 000 plants ha^{-1}; 35 kg ha^{-1} N; weeding twice	75	1517	1374	629
	50	1406	1374	483
	25	649	1374	-517
Planted on 1-15 December; 12 000 plants ha^{-1}; 35 kg ha^{-1} N; weeding once	75	1813	1400	995
	50	1433	1400	494
	25	608	1400	-597
Planted on 1-15 December; 12 000 plants ha^{-1}; 35 kg ha^{-1} N; weeding twice	75	1961	1424	1166
	50	1890	1424	1073
	25	833	1424	-324
Planted on 1-15 December; 12 000 plants ha^{-1}; 50 kg ha^{-1} N; weeding once	75	1857	1625	828
	50	1522	1625	385
	25	613	1625	-815
Planted on 1-15 December; 15 000 plants ha^{-1}; 35 kg ha^{-1} N; weeding once	75	1977	1449	1162
	50	1643	1449	721
	25	718	1449	-501
Planted on 1-15 December; 15 000 plants ha^{-1}; 35 kg ha^{-1} N; weeding twice	75	2214	1473	1451
	50	2080	1473	1274
	25	995	1473	-158
Planted on 1-15 December; 15 000 plants ha^{-1}; 50 kg ha^{-1} N; weeding once	75	2300	1674	1364
	50	1819	1674	729
	25	750	1674	-683

Planted on 1-15 December; 15 000 plants ha^{-1}; 50 kg ha^{-1} N; weeding twice	75	2376	1698	1440
	50	1957	1698	887
	25	751	1698	-706
Planted on 1-15 December; 18 000 plants ha^{-1}; 35 kg ha^{-1} N; weeding once	75	1808	1499	889
	50	1096	1499	-51
	25	246	1499	-1173
Planted on 1-15 December; 18 000 plants ha^{-1}; 35 kg ha^{-1} N; weeding twice	75	2243	1523	1440
	50	1955	1523	1059
	25	814	1523	-448
Planted on 1-15 December; 18 000 plants ha^{-1}; 50 kg ha^{-1} N; weeding once	75	2062	1724	999
	50	1398	1724	123
	25	615	1724	-911
Planted on 1-15 December; 18 000 plants ha^{-1}; 50 kg ha^{-1} N; weeding twice	75	2658	1748	1763
	50	2119	1748	1052
	25	873	1748	-595
Planted on 1-15 December; 21 000 plants ha^{-1}; 35 kg ha^{-1} N; weeding once	75	1895	1548	955
	50	1057	1548	-152
	25	176	1548	-1316
Planted on 1-15 December; 21 000 plants ha^{-1}; 35 kg ha^{-1} N; weeding twice	75	2316	1572	1487
	50	2036	1572	1117
	25	891	1572	-395
Planted on 1-15 December; 21 000 plants ha^{-1}; 50 kg ha^{-1} N; weeding once	75	2697	1773	1789
	50	1955	1773	810
	25	856	1773	-642
Planted on 1-15 December; 21 000 plants ha^{-1}; 50 kg ha^{-1} N; weeding twice	75	2931	1798	2074
	50	2530	1798	1545
	25	1364	1798	4

Table B8: Reference table for yield expectance, field costs and economic benefit under various sets of management practices during NN-AN rainfall conditions for Pioneer 3237

Management practices (For Pioneer 3237 cultivar)	Probability levels	Yield Expectance (kg ha^{-1})	Field Costs (Rand ha^{-1})	Economic benefit (Rand ha^{-1})
Planted on 1-15 November; 9 000 plants ha^{-1}; 35 kg ha^{-1} N; weeding twice	75	2283	1445	1571
	50	2086	1445	1311
	25	1692	1445	790
Planted on 1-15 November; 9 000 plants ha^{-1}; 50 kg ha^{-1} N; weeding twice	75	2708	1670	1907
	50	2141	1670	1158
	25	779	1670	-641
Planted on 1-15 November; 9 000 plants ha^{-1}; 50 kg ha^{-1} N; weeding thrice	75	2765	1694	1959
	50	2552	1694	1676
	25	2212	1694	1228
Planted on 1-15 November; 9 000 plants ha^{-1}; 75 kg ha^{-1} N; weeding twice	75	3129	2045	2088
	50	2640	2045	1442
	25	2365	2045	1079
Planted on 1-15 November; 12 000 plants ha^{-1}; 35 kg ha^{-1} N; weeding twice	75	2388	1518	1636
	50	2250	1518	1453
	25	1843	1518	916
Planted on 1-15 November; 12 000 plants ha^{-1}; 50 kg ha^{-1} N; weeding twice	75	2995	1743	2213
	50	2865	1743	2041
	25	2273	1743	1260
Planted on 1-15 November; 12 000 plants ha^{-1}; 75 kg ha^{-1} N; weeding twice	75	3682	2118	2746
	50	3290	2118	2228
	25	2957	2118	1788
Planted on 1-15 November; 12 000 plants ha^{-1}; 75 kg ha^{-1} N; weeding twice	75	3682	2142	2722
	50	3310	2142	2230
	25	3088	2142	1937
Planted on 1-15 November; 15 000 plants ha^{-1}; 50 kg ha^{-1} N; weeding twice	75	2973	1816	2110
	50	2426	1816	1389
	25	2172	1816	1053
Planted on 1-15 November; 15 000 plants ha^{-1}; 75 kg ha^{-1} N; weeding twice	75	3600	2191	2564
	50	3064	2191	1856
	25	2547	2191	1173
Planted on 1-15 November; 18 000 plants ha^{-1}; 35 kg ha^{-1} N; weeding twice	75	2436	1664	1554
	50	1761	1664	662
	25	718	1664	-717
Planted on 1-15 November; 18 000 plants ha^{-1}; 50 kg ha^{-1} N; weeding twice	75	3050	1889	2140
	50	2498	1889	1410
	25	2202	1889	1019

Planted on 1-15 November; 18 000 plants ha^{-1}; 75 kg ha^{-1} N; weeding thrice	75	4104	2289	3133
	50	3824	2289	2763
	25	3471	2289	2297
Planted on 1-15 November; 21 000 plants ha^{-1}; 35 kg ha^{-1} N; weeding twice	75	2495	1738	1119
	50	2294	1738	888
	25	1950	1738	495
Planted on 1-15 November; 21 000 plants ha^{-1}; 50 kg ha^{-1} N; two time of weeding control	75	3197	1963	1698
	50	3006	1963	1479
	25	2631	1963	1049
Planted on 1-15 November; 21 000 plants ha^{-1}; 75 kg ha^{-1} N; weeding twice	75	4169	2338	2436
	50	3827	2338	2044
	25	3325	2338	1469
Planted on 1-15 November; 21 000 plants ha^{-1}; 100 kg ha^{-1} N; weeding twice	75	4169	2338	2436
	50	3827	2338	2044
	25	3325	2338	1469
Planted on 16-30 November; 9 000 plants ha^{-1}; 35 kg ha^{-1} N; weeding twice	75	2189	1445	1446
	50	1773	1445	898
	25	832	1445	-347
Planted on 16-30 November; 9 000 plants ha^{-1}; 50 kg ha^{-1} N; weeding twice	75	2473	1670	1596
	50	1684	1670	554
	25	619	1670	-853
Planted on 16-30 November; 9 000 plants ha^{-1}; 50 kg ha^{-1} N; weeding thrice	75	2474	1694	1574
	50	2071	1694	1041
	25	1407	1694	165
Planted on 16-30 November; 9 000 plants ha^{-1}; 75 kg ha^{-1} N; weeding twice	75	2557	2045	1333
	50	2204	2045	867
	25	1621	2045	96
Planted on 16-30 November; 12 000 plants ha^{-1}; 35 kg ha^{-1} N; weeding twice	75	2360	1518	1600
	50	1916	1518	1013
	25	939	1518	-278
Planted on 16-30 November; 12 000 plants ha^{-1}; 50 kg ha^{-1} N; weeding twice	75	2857	1743	2031
	50	2322	1743	1325
	25	1249	1743	-93
Planted on 16-30 November; 12 000 plants ha^{-1}; 75 kg ha^{-1} N; weeding twice	75	3163	2118	2059
	50	2396	2118	1047
	25	1843	2118	316
Planted on 16-30 November; 12 000 plants ha^{-1}; 75 kg ha^{-1} N; weeding twice	75	3365	2142	2302
	50	2723	2142	1455
	25	2059	2142	578
Planted on 16-30 November; 15 000 plants ha^{-1}; 50 kg ha^{-1} N; weeding twice	75	3026	1816	2181
	50	2436	1816	1402
	25	1260	1816	-152
Planted on 16-30 November; 15 000 plants ha^{-1}; 75 kg ha^{-1} N; weeding twice	75	3755	2191	2769
	50	2829	2191	1545
	25	2074	2191	548
Planted on 16-30 November; 18 000 plants ha^{-1}; 35 kg ha^{-1} N; weeding twice	75	2464	1664	1590
	50	2053	1664	1048
	25	1328	1664	90
Planted on 16-30 November; 18 000 plants ha^{-1}; 50 kg ha^{-1} N; weeding twice	75	3054	1889	2144
	50	2524	1889	1444
	25	1318	1889	-149
Planted on 16-30 November; 18 000 plants ha^{-1}; 75 kg ha^{-1} N; weeding thrice	75	3935	2289	2909
	50	3755	2289	2671
	25	2143	2289	543
Planted on 16-30 November; 21 000 plants ha^{-1}; 35 kg ha^{-1} N; weeding twice	75	2507	1738	1575
	50	2092	1738	1025
	25	1481	1738	218
Planted on 16-30 November; 21 000 plants ha^{-1}; 50 kg ha^{-1} N; two time of weeding control	75	3137	1963	2181
	50	2585	1963	1452
	25	1459	1963	-36
Planted on 16-30 November; 21 000 plants ha^{-1}; 75 kg ha^{-1} N; weeding twice	75	4105	2338	3084
	50	3280	2338	1995
	25	1966	2338	260
Planted on 16-30 November; 21 000 plants ha^{-1}; 100 kg ha^{-1} N; weeding twice	75	4090	2712	2691
	50	3387	2712	1761
	25	2089	2712	47
Planted on 1-15 December; 9 000 plants ha^{-1}; 35 kg ha^{-1} N; weeding twice	75	1634	1445	713
	50	1262	1445	223
	25	158	1445	-1236

Planted on 1-15 December; 9 000 plants ha^{-1}; 50 kg ha^{-1} N; weeding twice	75	1869	1670	798
	50	1262	1670	-2
	25	190	1670	-1419
Planted on 1-15 December; 9 000 plants ha^{-1}; 50 kg ha^{-1} N; weeding thrice	75	2048	1694	1011
	50	1502	1694	290
	25	254	1694	-1359
Planted on 1-15 December; 9 000 plants ha^{-1}; 75 kg ha^{-1} N; weeding twice	75	1923	2045	494
	50	1387	2045	-213
	25	252	2045	-1713
Planted on 1-15 December; 12 000 plants ha^{-1}; 35 kg ha^{-1} N; weeding twice	75	1800	1518	860
	50	1411	1518	346
	25	200	1518	-1254
Planted on 1-15 December; 12 000 plants ha^{-1}; 50 kg ha^{-1} N; weeding twice	75	2124	1743	1062
	50	1634	1743	416
	25	219	1743	-1454
Planted on 1-15 December; 12 000 plants ha^{-1}; 75 kg ha^{-1} N; weeding twice	75	2371	2118	1014
	50	1693	2118	118
	25	300	2118	-1722
Planted on 1-15 December; 12 000 plants ha^{-1}; 75 kg ha^{-1} N; weeding twice	75	2604	2142	1297
	50	1946	2142	429
	25	328	2142	-1709
Planted on 1-15 December; 15 000 plants ha^{-1}; 50 kg ha^{-1} N; weeding twice	75	2355	1816	1294
	50	1812	1816	578
	25	255	1816	-1480
Planted on 1-15 December; 15 000 plants ha^{-1}; 75 kg ha^{-1} N; weeding twice	75	2706	2191	1383
	50	2101	2191	584
	25	336	2191	-1747
Planted on 1-15 December; 18 000 plants ha^{-1}; 35 kg ha^{-1} N; weeding twice	75	1942	1664	900
	50	1540	1664	370
	25	275	1664	-1301
Planted on 1-15 December; 18 000 plants ha^{-1}; 50 kg ha^{-1} N; weeding twice	75	2404	1889	1286
	50	1872	1889	583
	25	295	1889	-1499
Planted on 1-15 December; 18 000 plants ha^{-1}; 75 kg ha^{-1} N; weeding thrice	75	3306	2289	2078
	50	2583	2289	1124
	25	457	2289	-1686
Planted on 1-15 December; 21 000 plants ha^{-1}; 35 kg ha^{-1} N; weeding twice	75	2056	1738	978
	50	1590	1738	363
	25	284	1738	-1363
Planted on 1-15 December; 21 000 plants ha^{-1}; 50 kg ha^{-1} N; two time of weeding control	75	2521	1963	1367
	50	1905	1963	554
	25	340	1963	-1513
Planted on 1-15 December; 21 000 plants ha^{-1}; 75 kg ha^{-1} N; weeding twice	75	3204	2338	1895
	50	2181	2338	544
	25	388	2338	-1825
Planted on 1-15 December; 21 000 plants ha^{-1}; 100 kg ha^{-1} N; weeding twice	75	3318	2712	1671
	50	2344	2712	384
	25	489	2712	-2067

Table B9: Reference table for yield expectance, field costs and economic benefit under various sets of management practices during NN-NN rainfall conditions for PAN 6479

Management practices (For PAN 6479 cultivar)	Probability levels	Yield Expectance (kg ha^{-1})	Field Costs (Rand ha^{-1})	Economic benefit (Rand ha^{-1})
Planted on 1-15 November; 9 000 plants ha^{-1}; 35 kg ha^{-1} N; one times of weeding control	75	1151	1350	170
	50	972	1350	-66
	25	617	1350	-535
Planted on 1-15 November; 9 000 plants ha^{-1}; 35 kg ha^{-1} N; weeding twice	75	1438	1374	525
	50	1344	1374	402
	25	1150	1374	145
Planted on 1-15 November; 9 000 plants ha^{-1}; 50 kg ha^{-1} N; one times of weeding control	75	1145	1575	-62
	50	1011	1575	-240
	25	617	1575	-761
Planted on 1-15 November; 9 000 plants ha^{-1}; 50 kg ha^{-1} N; weeding twice	75	1339	1599	170
	50	1136	1599	-99
	25	465	1599	-985
Planted on 1-15 November; 12 000 plants ha^{-1}; 35 kg ha^{-1} N; weeding once	75	1462	1400	532
	50	1012	1400	-62
	25	667	1400	-519

Planted on 1-15 November; 12 000 plants ha^{-1}; 35 kg ha^{-1} N; weeding twice	75	1833	1424	998
	50	1673	1424	786
	25	1154	1424	101
Planted on 1-15 November; 12 000 plants ha^{-1}; 50 kg ha^{-1} N; weeding once	75	1457	1625	299
	50	1087	1625	-189
	25	665	1625	-747
Planted on 1-15 November; 12 000 plants ha^{-1}; 50 kg ha^{-1} N; weeding twice	75	1835	1649	775
	50	1584	1649	443
	25	1113	1649	-179
Planted on 1-15 November; 12 000 plants ha^{-1}; 50 kg ha^{-1} N; weeding thrice	75	1948	1673	900
	50	1693	1673	563
	25	1449	1673	240
Planted on 1-15 November; 15 000 plants ha^{-1}; 35 kg ha^{-1} N; weeding once	75	1529	1449	571
	50	1029	1449	-90
	25	710	1449	-511
Planted on 1-15 November; 15 000 plants ha^{-1}; 35 kg ha^{-1} N; weeding twice	75	2159	1473	1378
	50	1757	1473	848
	25	1483	1473	486
Planted on 1-15 November; 15 000 plants ha^{-1}; 50 kg ha^{-1} N; weeding once	75	1612	1674	455
	50	1348	1674	106
	25	904	1674	-480
Planted on 1-15 November; 15 000 plants ha^{-1}; 50 kg ha^{-1} N; weeding twice	75	2506	1698	1612
	50	2224	1698	1240
	25	1547	1698	345
Planted on 1-15 November; 18 000 plants ha^{-1}; 35 kg ha^{-1} N; weeding once	75	1757	1499	822
	50	1259	1499	164
	25	859	1499	-364
Planted on 1-15 November; 18 000 plants ha^{-1}; 35 kg ha^{-1} N; weeding twice	75	2219	1523	1408
	50	1779	1523	828
	25	1520	1523	484
Planted on 1-15 November; 18 000 plants ha^{-1}; 50 kg ha^{-1} N; weeding twice	75	2428	1748	1459
	50	2124	1748	1057
	25	1485	1748	214
Planted on 1-15 November; 21 000 plants ha^{-1}; 35 kg ha^{-1} N; weeding once	75	1929	1548	1000
	50	1307	1548	178
	25	833	1548	-448
Planted on 1-15 November; 21 000 plants ha^{-1}; 35 kg ha^{-1} N; weeding twice	75	2338	1572	1515
	50	2072	1572	1165
	25	1381	1572	252
Planted on 16-30 November; 9 000 plants ha^{-1}; 35 kg ha^{-1} N; one times of weeding control	75	1222	1350	264
	50	797	1350	-298
	25	458	1350	-746
Planted on 16-30 November; 9 000 plants ha^{-1}; 35 kg ha^{-1} N; weeding twice	75	1453	1374	545
	50	1391	1374	463
	25	1212	1374	227
Planted on 16-30 November; 12 000 plants ha^{-1}; 35 kg ha^{-1} N; weeding once	75	1441	1400	503
	50	1006	1400	-71
	25	496	1400	-744
Planted on 16-30 November; 12 000 plants ha^{-1}; 35 kg ha^{-1} N; weeding twice	75	1805	1424	961
	50	1691	1424	809
	25	1349	1424	358
Planted on 16-30 November; 12 000 plants ha^{-1}; 50 kg ha^{-1} N; weeding thrice	75	1909	1673	849
	50	1769	1673	663
	25	1597	1673	437
Planted on 16-30 November; 15 000 plants ha^{-1}; 35 kg ha^{-1} N; weeding once	75	1553	1449	602
	50	1091	1449	-9
	25	521	1449	-762
Planted on 16-30 November; 15 000 plants ha^{-1}; 35 kg ha^{-1} N; weeding twice	75	1968	1473	1126
	50	1761	1473	852
	25	1422	1473	405
Planted on 16-30 November; 15 000 plants ha^{-1}; 50 kg ha^{-1} N; weeding twice	75	2139	1473	1353
	50	1894	1473	1029
	25	1433	1473	420
Planted on 16-30 November; 15 000 plants ha^{-1}; 50 kg ha^{-1} N; weeding thrice	75	2209	1723	1195
	50	1950	1723	854
	25	1511	1723	273
Planted on 16-30 November; 18 000 plants ha^{-1}; 35 kg ha^{-1} N; weeding once	75	1616	1499	635
	50	1156	1499	28
	25	539	1499	-787

Planted on 16-30 November; 18 000 plants ha^{-1}; 35 kg ha^{-1} N; weeding twice	75	2043	1523	1175
	50	1839	1523	906
	25	1492	1523	447
Planted on 16-30 November; 18 000 plants ha^{-1}; 50 kg ha^{-1} N; weeding twice	75	2316	1748	1312
	50	2033	1748	938
	25	1409	1748	113
Planted on 16-30 November; 21 000 plants ha^{-1}; 35 kg ha^{-1} N; weeding once	75	1671	1548	659
	50	1171	1548	-2
	25	611	1548	-741
Planted on 16-30 November; 21 000 plants ha^{-1}; 35 kg ha^{-1} N; weeding twice	75	2116	1572	1223
	50	1803	1572	810
	25	1464	1572	361
Planted on 16-30 November; 21 000 plants ha^{-1}; 50 kg ha^{-1} N; weeding twice	75	2415	1798	1393
	50	2103	1798	981
	25	1331	1798	-39
Planted on 1-15 December; 9 000 plants ha^{-1}; 35 kg ha^{-1} N; one times of weeding control	75	1434	1350	544
	50	797	1350	-298
	25	175	1350	-1118
Planted on 1-15 December; 9 000 plants ha^{-1}; 35 kg ha^{-1} N; weeding twice	75	1477	1374	577
	50	1393	1374	466
	25	174	1374	-1144
Planted on 1-15 December; 12 000 plants ha^{-1}; 35 kg ha^{-1} N; weeding once	75	1610	1400	727
	50	817	1400	-320
	25	228	1400	-1099
Planted on 1-15 December; 12 000 plants ha^{-1}; 35 kg ha^{-1} N; weeding twice	75	1761	1424	902
	50	1629	1424	728
	25	227	1424	-1124
Planted on 1-15 December; 12 000 plants ha^{-1}; 50 kg ha^{-1} N; weeding thrice	75	1909	1673	849
	50	1772	1673	668
	25	229	1673	-1371
Planted on 1-15 December; 15 000 plants ha^{-1}; 35 kg ha^{-1} N; weeding once	75	1751	1449	864
	50	761	1449	-444
	25	278	1449	-1082
Planted on 1-15 December; 15 000 plants ha^{-1}; 35 kg ha^{-1} N; weeding twice	75	1862	1473	986
	50	1735	1473	819
	25	278	1473	-1107
Planted on 1-15 December; 15 000 plants ha^{-1}; 50 kg ha^{-1} N; weeding twice	75	1862	1473	986
	50	1735	1473	819
	25	278	1473	-1107
Planted on 1-15 December; 15 000 plants ha^{-1}; 50 kg ha^{-1} N; weeding thrice	75	2291	1723	1304
	50	1752	1723	592
	25	279	1723	-1354
Planted on 1-15 December; 18 000 plants ha^{-1}; 35 kg ha^{-1} N; weeding once	75	1797	1499	874
	50	710	1499	-561
	25	316	1499	-1082
Planted on 1-15 December; 18 000 plants ha^{-1}; 35 kg ha^{-1} N; weeding twice	75	1897	1523	983
	50	1644	1523	649
	25	314	1523	-1108
Planted on 16-30 November; 18 000 plants ha^{-1}; 50 kg ha^{-1} N; weeding twice	75	2231	1748	1199
	50	1753	1748	568
	25	328	1748	-1315
Planted on 1-15 December; 21 000 plants ha^{-1}; 35 kg ha^{-1} N; weeding once	75	1736	1548	745
	50	685	1548	-643
	25	333	1548	-1109
Planted on 1-15 December; 21 000 plants ha^{-1}; 35 kg ha^{-1} N; weeding twice	75	1947	1572	1000
	50	1704	1572	679
	25	334	1572	-1131
Planted on 1-15 December; 21 000 plants ha^{-1}; 50 kg ha^{-1} N; weeding twice	75	2379	1798	1345
	50	2025	1798	877
	25	374	1798	-1304
Planted on 1-15 December; 21 000 plants ha^{-1}; 50 kg ha^{-1} N; weeding thrice	75	2437	1822	1398
	50	2149	1822	1017
	25	373	1822	-1329

Table B10: Reference table for yield expectance, field costs and economic benefit under various sets of management practices during NN-NN rainfall conditions for Pioneer 3237

Management practices (For Pioneer 3237 cultivar)	Probability levels	Yield Expectance (kg ha^{-1})	Field Costs (Rand ha^{-1})	Economic benefit (Rand ha^{-1})
Planted on 1-15 November; 9 000 plants ha^{-1}; 35 kg ha^{-1} N; one times of weeding control	75	1912	1421	1105
	50	988	1421	-115
	25	235	1421	-1111
Planted on 1-15 November; 9 000 plants ha^{-1}; 35 kg ha^{-1} N; weeding twice	75	2292	1445	1582
	50	1739	1445	852
	25	773	1445	-424
Planted on 1-15 November; 9 000 plants ha^{-1}; 50 kg ha^{-1} N; weeding twice	75	2523	1670	1662
	50	694	1670	-753
	25	380	1670	-1169
Planted on 1-15 November; 9 000 plants ha^{-1}; 75 kg ha^{-1} N; weeding twice	75	2826	2045	1688
	50	2176	2045	829
	25	610	2045	-1239
Planted on 1-15 November; 12 000 plants ha^{-1}; 35 kg ha^{-1} N; weeding twice	75	2369	1518	1612
	50	1823	1518	890
	25	903	1518	-325
Planted on 1-15 November; 12 000 plants ha^{-1}; 50 kg ha^{-1} N; weeding twice	75	2796	1743	1950
	50	2334	1743	1339
	25	800	1743	-687
Planted on 1-15 November; 12 000 plants ha^{-1}; 75 kg ha^{-1} N; weeding twice	75	3086	2118	1959
	50	2477	2118	1154
	25	686	2118	-1212
Planted on 1-15 November; 15 000 plants ha^{-1}; 35 kg ha^{-1} N; weeding twice	75	2376	1591	1548
	50	1893	1591	910
	25	1005	1591	-264
Planted on 1-15 November; 15 000 plants ha^{-1}; 50 kg ha^{-1} N; weeding twice	75	2777	1816	1853
	50	2067	1816	914
	25	907	1816	-618
Planted on 1-15 November; 15 000 plants ha^{-1}; 75 kg ha^{-1} N; weeding twice	75	3072	2191	1866
	50	2532	2191	1154
	25	748	2191	-1203
Planted on 1-15 November; 18 000 plants ha^{-1}; 35 kg ha^{-1} N; weeding twice	75	2384	1664	1485
	50	1591	1664	437
	25	335	1664	-1221
Planted on 1-15 November; 18 000 plants ha^{-1}; 50 kg ha^{-1} N; weeding twice	75	2857	1889	1884
	50	2140	1889	937
	25	975	1889	-602
Planted on 1-15 November; 18 000 plants ha^{-1}; 75 kg ha^{-1} N; weeding twice	75	3035	2265	1745
	50	2582	2265	1147
	25	758	2265	-1264
Planted on 1-15 November; 21 000 plants ha^{-1}; 35 kg ha^{-1} N; weeding once	75	2303	1713	1329
	50	1100	1713	-260
	25	119	1713	-1556
Planted on 1-15 November; 21 000 plants ha^{-1}; 35 kg ha^{-1} N; weeding twice	75	2403	1738	1437
	50	1909	1738	784
	25	1133	1738	-241
Planted on 1-15 November; 21 000 plants ha^{-1}; 50 kg ha^{-1} N; weeding twice	75	2941	1963	1922
	50	2475	1963	1306
	25	1028	1963	-604
Planted on 1-15 November; 21 000 plants ha^{-1}; 75 kg ha^{-1} N; weeding twice	75	3820	2338	2708
	50	2662	2338	1179
	25	727	2338	-1378
Planted on 16-30 November; 9 000 plants ha^{-1}; 35 kg ha^{-1} N; weeding twice	75	1951	1445	1132
	50	1378	1445	375
	25	569	1445	-693
Planted on 16-30 November; 9 000 plants ha^{-1}; 50 kg ha^{-1} N; weeding twice	75	1741	1670	630
	50	627	1670	-841
	25	295	1670	-1280
Planted on 16-30 November; 9 000 plants ha^{-1}; 75 kg ha^{-1} N; weeding twice	75	2532	2045	1299
	50	1744	2045	258
	25	473	2045	-1420
Planted on 16-30 November; 12 000 plants ha^{-1}; 35 kg ha^{-1} N; weeding twice	75	1983	1518	1102
	50	1466	1518	418
	25	668	1518	-636

Planted on 16-30 November; 12 000 plants ha^{-1}; 50 kg ha^{-1} N; weeding twice	75	2446	1743	1488
	50	1822	1743	663
	25	562	1743	-1001
Planted on 16-30 November; 15 000 plants ha^{-1}; 75 kg ha^{-1} N; weeding twice	75	3341	2191	2222
	50	2251	2191	782
	25	573	2191	-1435
Planted on 16-30 November; 18 000 plants ha^{-1}; 50 kg ha^{-1} N; weeding twice	75	2613	1889	1562
	50	1916	1889	642
	25	842	1889	-777
Planted on 16-30 November; 18 000 plants ha^{-1}; 75 kg ha^{-1} N; weeding twice	75	3341	2265	2149
	50	2251	2265	709
	25	573	2265	-1508
Planted on 16-30 November; 18 000 plants ha^{-1}; 100 kg ha^{-1} N; weeding once	75	3222	2639	1617
	50	2299	2639	398
	25	533	2639	-1935
Planted on 16-30 November; 21 000 plants ha^{-1}; 35 kg ha^{-1} N; weeding once	75	2303	1713	1329
	50	1100	1713	-260
	25	119	1713	-1556
Planted on 16-30 November; 21 000 plants ha^{-1}; 75 kg ha^{-1} N; weeding twice	75	3419	2338	2179
	50	2383	2338	810
	25	519	2338	-1652

Table B11: Reference table for yield expectance, field costs and economic benefit under various sets of management practices during NN-BN rainfall conditions for PAN 6479

Management practices (For PAN 6479 cultivar)	Probability levels	Yield Expectance (kg ha^{-1})	Field Costs (Rand ha^{-1})	Economic benefit (Rand ha^{-1})
Planted on 1-15 November; 9 000 plants ha^{-1}; 35 kg ha^{-1} N; weeding once	75	854	1350	-222
	50	622	1350	-528
	25	489	1350	-704
Planted on 1-15 November; 9 000 plants ha^{-1}; 35 kg ha^{-1} N; weeding twice	75	1305	1374	349
	50	1197	1374	206
	25	974	1374	-87
Planted on 1-15 November; 12 000 plants ha^{-1}; 35 kg ha^{-1} N; weeding once	75	933	1400	-167
	50	663	1400	-524
	25	433	1400	-827
Planted on 1-15 November; 12 000 plants ha^{-1}; 35 kg ha^{-1} N; weeding twice	75	1517	1424	580
	50	1254	1424	233
	25	964	1424	-150
Planted on 1-15 November; 15 000 plants ha^{-1}; 35 kg ha^{-1} N; weeding once	75	865	1449	-307
	50	620	1449	-630
	25	376	1449	-953
Planted on 1-15 November; 15 000 plants ha^{-1}; 35 kg ha^{-1} N; weeding twice	75	1527	1473	543
	50	1316	1473	265
	25	973	1473	-188
Planted on 1-15 November; 15 000 plants ha^{-1}; 50 kg ha^{-1} N; weeding twice	75	1684	1698	526
	50	1350	1698	84
	25	1135	1698	-199
Planted on 1-15 November; 18 000 plants ha^{-1}; 35 kg ha^{-1} N; weeding once	75	870	1499	-350
	50	608	1499	-695
	25	336	1499	-1055
Planted on 1-15 November; 18 000 plants ha^{-1}; 35 kg ha^{-1} N; weeding twice	75	1481	1523	434
	50	1360	1523	273
	25	891	1523	-346
Planted on 1-15 November; 21 000 plants ha^{-1}; 35 kg ha^{-1} N; weeding once	75	794	1548	-499
	50	559	1548	-810
	25	296	1548	-1157
Planted on 1-15 November; 21 000 plants ha^{-1}; 35 kg ha^{-1} N; weeding twice	75	1452	1572	345
	50	1323	1572	175
	25	817	1572	-494
Planted on 16-30 November; 9 000 plants ha^{-1}; 35 kg ha^{-1} N; weeding once	75	1289	1350	352
	50	982	1350	-53
	25	508	1350	-680
Planted on 16-30 November; 9 000 plants ha^{-1}; 35 kg ha^{-1} N; weeding twice	75	1423	1374	505
	50	1250	1374	276
	25	1137	1374	127
Planted on 16-30 November; 12 000 plants ha^{-1}; 35 kg ha^{-1} N; weeding once	75	1416	1400	471
	50	1091	1400	42
	25	462	1400	-790

Planted on 16-30 November; 12 000 plants ha^{-1}; 35 kg ha^{-1} N; weeding twice	75	1785	1424	934
	50	1410	1424	439
	25	1138	1424	80
Planted on 16-30 November; 15 000 plants ha^{-1}; 35 kg ha^{-1} N; weeding once	75	1464	1449	485
	50	1118	1449	27
	25	402	1449	-918
Planted on 16-30 November; 15 000 plants ha^{-1}; 35 kg ha^{-1} N; weeding twice	75	1811	1473	919
	50	1440	1473	429
	25	1139	1473	31
Planted on 16-30 November; 15 000 plants ha^{-1}; 50 kg ha^{-1} N; weeding twice	75	1811	1698	694
	50	1403	1698	154
	25	1116	1698	-224
Planted on 16-30 November; 18 000 plants ha^{-1}; 35 kg ha^{-1} N; weeding once	75	1370	1499	311
	50	1187	1499	69
	25	350	1499	-1036
Planted on 16-30 November; 18 000 plants ha^{-1}; 35 kg ha^{-1} N; weeding twice	75	1939	1523	1038
	50	1380	1523	299
	25	1014	1523	-184
Planted on 16-30 November; 21 000 plants ha^{-1}; 35 kg ha^{-1} N; weeding once	75	1282	1548	145
	50	1146	1548	-35
	25	306	1548	-1145
Planted on 16-30 November; 21 000 plants ha^{-1}; 35 kg ha^{-1} N; weeding twice	75	1980	1572	1043
	50	1308	1572	155
	25	914	1572	-365

Table B12: Reference table for yield expectance, field costs and economic benefit under various sets of management practices during NN-BN rainfall conditions for Pioneer 3237

Management practices (For Pioneer 3237 cultivar)	**Probability levels**	**Yield Expectance (kg ha^{-1})**	**Field Costs (Rand ha^{-1})**	**Economic benefit (Rand ha^{-1})**
Planted on 1-15 November; 9 000 plants ha^{-1}; 35 kg ha^{-1} N; weeding once	75	1052	1421	-31
	50	758	1421	-420
	25	499	1421	-762
Planted on 1-15 November; 9 000 plants ha^{-1}; 35 kg ha^{-1} N; weeding twice	75	1935	1445	1112
	50	1793	1445	923
	25	1621	1445	696
Planted on 1-15 November; 9 000 plants ha^{-1}; 35 kg ha^{-1} N; weeding thrice	75	2168	1469	1395
	50	1888	1469	1025
	25	1702	1469	779
Planted on 1-15 November; 9 000 plants ha^{-1}; 50 kg ha^{-1} N; weeding thrice	75	2366	1694	1432
	50	1857	1694	759
	25	1778	1694	655
Planted on 1-15 November; 9 000 plants ha^{-1}; 75 kg ha^{-1} N; weeding thrice	75	2404	2069	1107
	50	1858	2069	386
	25	1547	2069	-26
Planted on 1-15 November; 12 000 plants ha^{-1}; 35 kg ha^{-1} N; weeding twice	75	2106	1743	1038
	50	1715	1743	522
	25	1496	1743	233
Planted on 1-15 November; 12 000 plants ha^{-1}; 50 kg ha^{-1} N; weeding thrice	75	2438	1767	1454
	50	1838	1767	661
	25	1573	1767	310
Planted on 16-30 November; 9 000 plants ha^{-1}; 35 kg ha^{-1} N; weeding once	75	1317	1421	319
	50	826	1421	-330
	25	413	1421	-875
Planted on 16-30 November; 9 000 plants ha^{-1}; 35 kg ha^{-1} N; weeding twice	75	1929	1445	1103
	50	1697	1445	796
	25	546	1445	-723
Planted on 16-30 November; 9 000 plants ha^{-1}; 35 kg ha^{-1} N; weeding thrice	75	1879	1469	1013
	50	1670	1469	737
	25	627	1469	-641
Planted on 16-30 November; 9 000 plants ha^{-1}; 50 kg ha^{-1} N; weeding thrice	75	2171	1694	1174
	50	1765	1694	637
	25	587	1694	-919
Planted on 16-30 November; 9 000 plants ha^{-1}; 75 kg ha^{-1} N; weeding thrice	75	2128	2069	742
	50	1685	2069	157
	25	552	2069	-1340
Planted on 16-30 November; 12 000 plants ha^{-1}; 35 kg ha^{-1} N; weeding twice	75	2196	1743	1157
	50	1700	1743	502
	25	710	1743	-805

Planted on 16-30 November; 12 000 plants ha^{-1}; 50 kg ha^{-1} N; weeding thrice	75	2287	1767	1254
	50	1746	1767	539
	25	709	1767	-831

Table B13: Reference table for yield expectance, field costs and economic benefit under various sets of management practices during BN-AN rainfall conditions for PAN 6479

Management practices (For PAN 6479 cultivar)	Probability levels	Yield Expectance (kg ha^{-1})	Field Costs (Rand ha^{-1})	Economic benefit (Rand ha^{-1})
Planted on 1-15 November; 12 000 plants ha^{-1}; 35 kg ha^{-1} N; weeding once	75	1767	1400	935
	50	1451	1400	517
	25	967	1400	-122
Planted on 1-15 November; 12 000 plants ha^{-1}; 35 kg ha^{-1} N; weeding twice	75	1861	1424	1035
	50	1597	1424	685
	25	1342	1424	349
Planted on 1-15 November; 12 000 plants ha^{-1}; 50 kg ha^{-1} N; weeding once	75	1756	1625	694
	50	1443	1625	282
	25	951	1625	-369
Planted on 1-15 November; 12 000 plants ha^{-1}; 50 kg ha^{-1} N; weeding twice	75	1851	1649	796
	50	1611	1649	480
	25	1322	1649	97
Planted on 1-15 November; 15 000 plants ha^{-1}; 35 kg ha^{-1} N; weeding once	75	1970	1449	1152
	50	1616	1449	685
	25	1032	1449	-86
Planted on 1-15 November; 15 000 plants ha^{-1}; 35 kg ha^{-1} N; weeding twice	75	2156	1473	1375
	50	1940	1473	1089
	25	1513	1473	525
Planted on 1-15 November; 15 000 plants ha^{-1}; 50 kg ha^{-1} N; weeding once	75	2070	1674	1060
	50	1603	1674	444
	25	1086	1674	-240
Planted on 1-15 November; 15 000 plants ha^{-1}; 50 kg ha^{-1} N; weeding twice	75	2411	1698	1486
	50	2074	1698	1042
	25	1590	1698	402
Planted on 1-15 November; 18 000 plants ha^{-1}; 35 kg ha^{-1} N; weeding once	75	2090	1499	1262
	50	1732	1499	789
	25	1066	1499	-91
Planted on 1-15 November; 18 000 plants ha^{-1}; 35 kg ha^{-1} N; weeding twice	75	2378	1523	1619
	50	2082	1523	1227
	25	1521	1523	487
Planted on 1-15 November; 18 000 plants ha^{-1}; 50 kg ha^{-1} N; weeding once	75	2420	1724	1472
	50	2336	1724	1362
	25	1419	1724	150
Planted on 1-15 November; 18 000 plants ha^{-1}; 50 kg ha^{-1} N; weeding twice	75	2311	1748	1304
	50	2201	1748	1159
	25	1588	1748	350
Planted on 1-15 November; 21 000 plants ha^{-1}; 35 kg ha^{-1} N; weeding once	75	2441	1548	1676
	50	1720	1548	724
	25	1039	1548	-176
Planted on 1-15 November; 21 000 plants ha^{-1}; 35 kg ha^{-1} N; weeding twice	75	2536	1572	1778
	50	2208	1572	1344
	25	1477	1572	379
Planted on 1-15 November; 21 000 plants ha^{-1}; 50 kg ha^{-1} N; weeding once	75	2439	1773	1448
	50	1705	1773	479
	25	1292	1773	-67
Planted on 1-15 November; 21 000 plants ha^{-1}; 50 kg ha^{-1} N; weeding twice	75	2452	1798	1441
	50	2358	1798	1317
	25	1596	1798	311
Planted on 1-15 November; 21 000 plants ha^{-1}; 75 kg ha^{-1} N; weeding once	75	2405	2149	1029
	50	1705	2149	104
	25	1329	2149	-393
Planted on 1-15 November; 21 000 plants ha^{-1}; 75 kg ha^{-1} N; weeding twice	75	2449	2173	1062
	50	2363	2173	948
	25	1617	2173	-37
Planted on 16-30 November; 12 000 plants ha^{-1}; 35 kg ha^{-1} N; weeding once	75	1655	1400	787
	50	1406	1400	458
	25	715	1400	-455
Planted on 16-30 November; 12 000 plants ha^{-1}; 35 kg ha^{-1} N; weeding twice	75	1912	1424	1102
	50	1561	1424	638
	25	793	1424	-376

Planted on 16-30 November; 12 000 plants ha^{-1}; 50 kg ha^{-1} N; weeding once	75	1629	1625	527
	50	1309	1625	104
	25	900	1625	-436
Planted on 16-30 November; 12 000 plants ha^{-1}; 50 kg ha^{-1} N; weeding twice	75	1943	1649	918
	50	1607	1649	474
	25	1252	1649	5
Planted on 16-30 November; 15 000 plants ha^{-1}; 35 kg ha^{-1} N; weeding once	75	1750	1449	862
	50	1551	1449	600
	25	703	1449	-521
Planted on 16-30 November; 15 000 plants ha^{-1}; 35 kg ha^{-1} N; weeding twice	75	2068	1473	1258
	50	1760	1473	852
	25	867	1473	-328
Planted on 16-30 November; 15 000 plants ha^{-1}; 50 kg ha^{-1} N; weeding once	75	1739	1674	623
	50	1470	1674	267
	25	933	1674	-442
Planted on 16-30 November; 15 000 plants ha^{-1}; 50 kg ha^{-1} N; weeding twice	75	2327	1698	1375
	50	1778	1698	650
	25	1341	1698	73
Planted on 16-30 November; 18 000 plants ha^{-1}; 35 kg ha^{-1} N; weeding once	75	1846	1499	940
	50	1443	1499	407
	25	755	1499	-501
Planted on 16-30 November; 18 000 plants ha^{-1}; 35 kg ha^{-1} N; weeding twice	75	2260	1523	1463
	50	1817	1523	877
	25	892	1523	-345
Planted on 16-30 November; 18 000 plants ha^{-1}; 50 kg ha^{-1} N; weeding once	75	1809	1724	666
	50	1517	1724	280
	25	916	1724	-514
Planted on 16-30 November; 18 000 plants ha^{-1}; 50 kg ha^{-1} N; weeding twice	75	2570	1748	1647
	50	2041	1748	948
	25	1402	1748	104
Planted on 16-30 November; 21 000 plants ha^{-1}; 35 kg ha^{-1} N; weeding once	75	1865	1548	915
	50	1408	1548	312
	25	797	1548	-496
Planted on 16-30 November; 21 000 plants ha^{-1}; 35 kg ha^{-1} N; weeding twice	75	2319	1572	1491
	50	1840	1572	858
	25	891	1572	-395
Planted on 16-30 November; 21 000 plants ha^{-1}; 50 kg ha^{-1} N; weeding once	75	1939	1773	788
	50	1588	1773	324
	25	865	1773	-631
Planted on 16-30 November; 21 000 plants ha^{-1}; 50 kg ha^{-1} N; weeding twice	75	2692	1798	1759
	50	2139	1798	1028
	25	1375	1798	19
Planted on 16-30 November; 21 000 plants ha^{-1}; 75 kg ha^{-1} N; weeding once	75	1917	2149	383
	50	1498	2149	-170
	25	1236	2149	-516
Planted on 16-30 November; 21 000 plants ha^{-1}; 75 kg ha^{-1} N; weeding twice	75	2657	2173	1337
	50	2132	2173	644
	25	1521	2173	-163
Planted on 1-15 December; 12 000 plants ha^{-1}; 35 kg ha^{-1} N; weeding once	75	1767	1400	935
	50	1451	1400	517
	25	967	1400	-122
Planted on 1-15 December; 12 000 plants ha^{-1}; 35 kg ha^{-1} N; weeding twice	75	1861	1424	1035
	50	1597	1424	685
	25	1342	1424	349
Planted on 1-15 December; 12 000 plants ha^{-1}; 50 kg ha^{-1} N; weeding once	75	1756	1625	694
	50	1443	1625	282
	25	951	1625	-369
Planted on 1-15 December; 12 000 plants ha^{-1}; 50 kg ha^{-1} N; weeding twice	75	1851	1649	796
	50	1611	1649	480
	25	1322	1649	97
Planted on 1-15 December; 15 000 plants ha^{-1}; 35 kg ha^{-1} N; weeding once	75	1970	1449	1152
	50	1616	1449	685
	25	1032	1449	-86
Planted on 1-15 December; 15 000 plants ha^{-1}; 35 kg ha^{-1} N; weeding twice	75	2156	1473	1375
	50	1940	1473	1089
	25	1513	1473	525
Planted on 1-15 December; 15 000 plants ha^{-1}; 50 kg ha^{-1} N; weeding once	75	2070	1674	1060
	50	1603	1674	444
	25	1086	1674	-240

Planted on 1-15 December; 15 000 plants ha^{-1}; 50 kg ha^{-1} N; weeding twice	75	2411	1698	1486
	50	2074	1698	1042
	25	1590	1698	402
Planted on 1-15 December; 18 000 plants ha^{-1}; 35 kg ha^{-1} N; weeding once	75	2090	1499	1262
	50	1732	1499	789
	25	1066	1499	-91
Planted on 1-15 December; 18 000 plants ha^{-1}; 35 kg ha^{-1} N; weeding twice	75	2378	1523	1619
	50	2082	1523	1227
	25	1521	1523	487
Planted on 1-15 December; 18 000 plants ha^{-1}; 50 kg ha^{-1} N; weeding once	75	2420	1724	1472
	50	2336	1724	1362
	25	1419	1724	150
Planted on 1-15 December; 18 000 plants ha^{-1}; 50 kg ha^{-1} N; weeding twice	75	2311	1748	1304
	50	2201	1748	1159
	25	1588	1748	350
Planted on 1-15 December; 21 000 plants ha^{-1}; 35 kg ha^{-1} N; weeding once	75	2441	1548	1676
	50	1720	1548	724
	25	1039	1548	-176
Planted on 1-15 December; 21 000 plants ha^{-1}; 35 kg ha^{-1} N; weeding twice	75	2536	1572	1778
	50	2208	1572	1344
	25	1477	1572	379
Planted on 1-15 December; 21 000 plants ha^{-1}; 50 kg ha^{-1} N; weeding once	75	2439	1773	1448
	50	1705	1773	479
	25	1292	1773	-67
Planted on 1-15 December; 21 000 plants ha^{-1}; 50 kg ha^{-1} N; weeding twice	75	2452	1798	1441
	50	2358	1798	1317
	25	1596	1798	311
Planted on 1-15 December; 21 000 plants ha^{-1}; 75 kg ha^{-1} N; weeding once	75	2405	2149	1029
	50	1705	2149	104
	25	1329	2149	-393
Planted on 1-15 December; 21 000 plants ha^{-1}; 75 kg ha^{-1} N; weeding twice	75	2449	2173	1062
	50	2363	2173	948
	25	1617	2173	-37

Table B14: Reference table for yield expectance, field costs and economic benefit under various sets of management practices during BN-AN rainfall conditions for Pioneer 3237

Management practices (For Pioneer 3237 cultivar)	Probability levels	Yield Expectance (kg ha^{-1})	Field Costs (Rand ha^{-1})	Economic benefit (Rand ha^{-1})
Planted on 1-15 November; 9 000 plants ha^{-1}; 35 kg ha^{-1} N; weeding once	75	1843	1421	1014
	50	1256	1421	238
	25	686	1421	-515
Planted on 1-15 November; 9 000 plants ha^{-1}; 35 kg ha^{-1} N; weeding twice	75	2216	1445	1482
	50	1706	1445	809
	25	1124	1445	40
Planted on 1-15 November; 9 000 plants ha^{-1}; 50 kg ha^{-1} N; weeding once	75	2509	1646	1669
	50	1416	1646	224
	25	790	1646	-602
Planted on 1-15 November; 9 000 plants ha^{-1};50 kg ha^{-1} N; weeding thrice	75	2751	1694	1940
	50	2000	1694	948
	25	1339	1694	74
Planted on 1-15 November; 12 000 plants ha^{-1}; 35 kg ha^{-1} N; weeding twice	75	2399	1518	1651
	50	1922	1518	1021
	25	1248	1518	130
Planted on 1-15 November; 12 000 plants ha^{-1}; 50 kg ha^{-1} N; weeding twice	75	2893	1743	2079
	50	2072	1743	994
	25	1502	1743	241
Planted on 1-15 November; 12 000 plants ha^{-1}; 75 kg ha^{-1} N; weeding thrice	75	3644	2142	2672
	50	2646	2142	1353
	25	1603	2142	-25
Planted on 1-15 November; 15 000 plants ha^{-1}; 35 kg ha^{-1} N; weeding once	75	1914	1567	962
	50	1428	1567	319
	25	795	1567	-517
Planted on 1-15 November; 15 000 plants ha^{-1}; 35 kg ha^{-1} N; weeding twice	75	2501	1591	1712
	50	1948	1591	982
	25	1321	1591	154
Planted on 1-15 November; 15 000 plants ha^{-1}; 50 kg ha^{-1} N; weeding twice	75	2999	1816	2145
	50	2442	1816	1409
	25	1321	1816	-71

Planted on 1-15 November; 15 000 plants ha^{-1}; 75 kg ha^{-1} N; weeding once	75	3182	2168	2036
	50	1626	2168	-20
	25	917	2168	-957
Planted on 1-15 November; 15 000 plants ha^{-1}; 75 kg ha^{-1} N; weeding thrice	75	3506	2216	2415
	50	2980	2216	1721
	25	1881	2216	269
Planted on 1-15 November; 18 000 plants ha^{-1}; 50 kg ha^{-1} N; weeding once	75	2629	1865	1608
	50	1569	1865	207
	25	836	1865	-761
Planted on 1-15 November; 18 000 plants ha^{-1}; 50 kg ha^{-1} N; weeding twice	75	3070	1889	2166
	50	2557	1889	1488
	25	1373	1889	-76
Planted on 1-15 November; 18 000 plants ha^{-1}; 75 kg ha^{-1} N; weeding thrice	75	4187	2289	3242
	50	3226	2289	1973
	25	1992	2289	342
Planted on 1-15 November; 21 000 plants ha^{-1}; 35 kg ha^{-1} N; weeding twice	75	2582	1738	1673
	50	1943	1738	829
	25	1332	1738	22
Planted on 1-15 November; 21 000 plants ha^{-1}; 50 kg ha^{-1} N; weeding twice	75	3341	1963	2450
	50	2591	1963	1460
	25	1637	1963	200
Planted on 1-15 November; 21 000 plants ha^{-1}; 75 kg ha^{-1} N; weeding thrice	75	4336	2362	3367
	50	3393	2362	2120
	25	2028	2362	317
Planted on 16-30 November; 9 000 plants ha^{-1}; 35 kg ha^{-1} N; weeding once	75	1496	1421	556
	50	779	1421	-392
	25	168	1421	-1199
Planted on 16-30 November; 9 000 plants ha^{-1}; 35 kg ha^{-1} N; weeding twice	75	1706	1445	809
	50	1190	1445	128
	25	286	1445	-1067
Planted on 16-30 November; 9 000 plants ha^{-1}; 50 kg ha^{-1} N; weeding once	75	1529	1646	373
	50	867	1646	-501
	25	243	1646	-1326
Planted on 16-30 November; 9 000 plants ha^{-1};50 kg ha^{-1} N; weeding thrice	75	1912	1694	832
	50	1411	1694	170
	25	706	1694	-761
Planted on 16-30 November; 12 000 plants ha^{-1}; 35 kg ha^{-1} N; weeding twice	75	1864	1518	944
	50	1291	1518	187
	25	303	1518	-1118
Planted on 16-30 November; 12 000 plants ha^{-1}; 50 kg ha^{-1} N; weeding twice	75	2344	1743	1353
	50	1572	1743	333
	25	578	1743	-980
Planted on 16-30 November; 12 000 plants ha^{-1}; 75 kg ha^{-1} N; weeding thrice	75	2531	2142	1201
	50	1784	2142	214
	25	1114	2142	-671
Planted on 16-30 November; 15 000 plants ha^{-1}; 35 kg ha^{-1} N; weeding once	75	1591	1567	534
	50	885	1567	-398
	25	269	1567	-1212
Planted on 16-30 November; 15 000 plants ha^{-1}; 35 kg ha^{-1} N; weeding twice	75	1936	1591	966
	50	1330	1591	166
	25	306	1591	-1187
Planted on 16-30 November; 15 000 plants ha^{-1}; 50 kg ha^{-1} N; weeding twice	75	2481	1816	1461
	50	1702	1816	431
	25	568	1816	-1067
Planted on 16-30 November; 15 000 plants ha^{-1}; 75 kg ha^{-1} N; weeding once	75	2065	2167	561
	50	1359	2167	-372
	25	145	2167	-1976
Planted on 16-30 November; 15 000 plants ha^{-1}; 75 kg ha^{-1} N; weeding thrice	75	3056	2216	1821
	50	2199	2216	689
	25	1283	2216	-520
Planted on 16-30 November; 18 000 plants ha^{-1}; 50 kg ha^{-1} N; weeding once	75	2138	1865	959
	50	1138	1865	-362
	25	267	1865	-1513
Planted on 16-30 November; 18 000 plants ha^{-1}; 50 kg ha^{-1} N; weeding twice	75	2590	1889	1531
	50	1733	1889	399
	25	553	1889	-1160
Planted on 16-30 November; 18 000 plants ha^{-1}; 75 kg ha^{-1} N; weeding thrice	75	3277	2289	2040
	50	2303	2289	753
	25	1411	2289	-425

Planted on 16-30 November; 21 000 plants ha^{-1}; 35 kg ha^{-1} N; weeding twice	75	1981	1738	879
	50	1383	1738	90
	25	301	1738	-1340
Planted on 16-30 November; 21 000 plants ha^{-1}; 50 kg ha^{-1} N; weeding twice	75	2678	1963	1575
	50	1767	1963	371
	25	536	1963	-1255
Planted on 16-30 November; 21 000 plants ha^{-1}; 75 kg ha^{-1} N; weeding thrice	75	3387	2362	2112
	50	2457	2362	884
	25	1511	2362	-366
Planted on 1-15 December; 9 000 plants ha^{-1}; 35 kg ha^{-1} N; weeding once	75	1035	1421	-54
	50	621	1421	-600
	25	41	1421	-1367
Planted on 1-15 December; 9 000 plants ha^{-1}; 35 kg ha^{-1} N; weeding twice	75	1297	1445	269
	50	778	1445	-417
	25	339	1445	-997
Planted on 1-15 December; 9 000 plants ha^{-1}; 50 kg ha^{-1} N; weeding twice	75	1610	1670	457
	50	850	1670	-547
	25	426	1670	-1107
Planted on 1-15 December; 12 000 plants ha^{-1}; 35 kg ha^{-1} N; weeding once	75	1212	1494	107
	50	698	1494	-571
	25	42	1494	-1439
Planted on 1-15 December; 12 000 plants ha^{-1}; 35 kg ha^{-1} N; weeding twice	75	1368	1518	289
	50	868	1518	-372
	25	380	1518	-1016
Planted on 1-15 December; 12 000 plants ha^{-1}; 50 kg ha^{-1} N; weeding twice	75	1779	1743	606
	50	1020	1743	-396
	25	457	1743	-1140
Planted on 1-15 December; 12 000 plants ha^{-1}; 75 kg ha^{-1} N; weeding twice	75	1981	2118	499
	50	1112	2118	-649
	25	386	2118	-1609
Planted on 1-15 December; 15 000 plants ha^{-1}; 35 kg ha^{-1} N; weeding once	75	1339	1567	202
	50	772	1567	-547
	25	38	1567	-1517
Planted on 1-15 December; 15 000 plants ha^{-1}; 35 kg ha^{-1} N; weeding twice	75	1450	1591	324
	50	906	1591	-394
	25	414	1591	-1044
Planted on 1-15 December; 15 000 plants ha^{-1}; 50 kg ha^{-1} N; weeding twice	75	1857	1591	861
	50	1111	1591	-123
	25	491	1591	-942
Planted on 1-15 December; 15 000 plants ha^{-1}; 75 kg ha^{-1} N; weeding twice	75	2065	2191	537
	50	1348	2191	-410
	25	294	2191	-1804
Planted on 1-15 December; 15 000 plants ha^{-1}; 75 kg ha^{-1} N; weeding thrice	75	2247	2216	753
	50	1322	2216	-470
	25	700	2216	-1290
Planted on 1-15 December; 18 000 plants ha^{-1}; 50 kg ha^{-1} N; weeding twice	75	1888	1889	604
	50	1187	1889	-322
	25	452	1889	-1293
Planted on 1-15 December; 18 000 plants ha^{-1}; 50 kg ha^{-1} N; weeding thrice	75	1905	1914	603
	50	1211	1914	-314
	25	551	1914	-1186
Planted on 1-15 December; 18 000 plants ha^{-1}; 75 kg ha^{-1} N; weeding thrice	75	2385	2289	862
	50	1446	2289	-379
	25	738	2289	-1313
Planted on 1-15 December; 21 000 plants ha^{-1}; 35 kg ha^{-1} N; weeding twice	75	1543	1738	300
	50	946	1738	-488
	25	417	1738	-1187
Planted on 1-15 December; 21 000 plants ha^{-1}; 50 kg ha^{-1} N; weeding thrice	75	1950	1987	589
	50	1275	1987	-303
	25	570	1987	-1234
Planted on 1-15 December; 21 000 plants ha^{-1}; 75 kg ha^{-1} N; weeding thrice	75	2515	2362	960
	50	1511	2362	-366
	25	769	2362	-1345

Table B15: Reference table for yield expectance, field costs and economic benefit under various sets of management practices during BN-NN rainfall conditions for PAN 6479

Management practices (For PAN 6479 cultivar)	Probability levels	Yield Expectance (kg ha^{-1})	Field Costs (Rand ha^{-1})	Economic benefit (Rand ha^{-1})
Planted on 1-15 November; 9 000 plants ha^{-1}; 35 kg ha^{-1} N; weeding twice	75	1335	1374	389
	50	1252	1374	280
	25	1026	1374	-19
Planted on 1-15 November; 9 000 plants ha^{-1}; 35 kg ha^{-1} N; weeding thrice	75	1429	1398	490
	50	1388	1398	435
	25	956	1398	-136
Planted on 1-15 November; 12 000 plants ha^{-1}; 35 kg ha^{-1} N; weeding twice	75	1786	1424	935
	50	1581	1424	665
	25	1279	1424	265
Planted on 1-15 November; 12 000 plants ha^{-1}; 35 kg ha^{-1} N; weeding thrice	75	1871	1448	1024
	50	1662	1448	748
	25	1368	1448	359
Planted on 1-15 November; 12 000 plants ha^{-1}; 50 kg ha^{-1} N; weeding twice	75	1801	1649	730
	50	1353	1649	138
	25	1112	1649	-181
Planted on 1-15 November; 15 000 plants ha^{-1}; 35 kg ha^{-1} N; weeding twice	75	2000	1473	1169
	50	1794	1473	897
	25	1443	1473	432
Planted on 1-15 November; 15 000 plants ha^{-1}; 50 kg ha^{-1} N; weeding twice	75	2266	1698	1294
	50	1782	1698	655
	25	1193	1698	-123
Planted on 1-15 November; 18 000 plants ha^{-1}; 35 kg ha^{-1} N; weeding once	75	1611	1499	629
	50	1134	1499	-1
	25	801	1499	-441
Planted on 1-15 November; 18 000 plants ha^{-1}; 35 kg ha^{-1} N; weeding thrice	75	2125	1547	1260
	50	1737	1547	747
	25	363	1547	-1067
Planted on 1-15 November; 18 000 plants ha^{-1}; 50 kg ha^{-1} N; weeding twice	75	2365	1748	1376
	50	1769	1748	588
	25	1329	1748	7
Planted on 16-30 November; 9 000 plants ha^{-1}; 35 kg ha^{-1} N; weeding once	75	1262	1350	317
	50	870	1350	-200
	25	439	1350	-771
Planted on 16-30 November; 9 000 plants ha^{-1}; 35 kg ha^{-1} N; weeding twice	75	1487	1374	590
	50	1321	1374	371
	25	568	1374	-624
Planted on 16-30 November; 12 000 plants ha^{-1}; 35 kg ha^{-1} N; one times of weeding control	75	1459	1400	527
	50	926	1400	-177
	25	386	1400	-890
Planted on 16-30 November; 12 000 plants ha^{-1}; 35 kg ha^{-1} N; weeding twice	75	1856	1424	1027
	50	1593	1424	680
	25	721	1424	-472
Planted on 16-30 November; 12 000 plants ha^{-1}; 50 kg ha^{-1} N; weeding twice	75	1861	1649	810
	50	1466	1649	288
	25	715	1649	-704
Planted on 16-30 November; 15 000 plants ha^{-1}; 35 kg ha^{-1} N; weeding twice	75	2009	1473	1180
	50	1635	1473	687
	25	767	1473	-460
Planted on 16-30 November; 15 000 plants ha^{-1}; 50 kg ha^{-1} N; weeding twice	75	2234	1698	1253
	50	1637	1698	464
	25	740	1698	-721
Planted on 16-30 November; 18 000 plants ha^{-1}; 35 kg ha^{-1} N; weeding once	75	1654	1499	687
	50	951	1499	-242
	25	292	1499	-1114
Planted on 16-30 November; 18 000 plants ha^{-1}; 35 kg ha^{-1} N; weeding twice	75	2067	1523	1207
	50	1664	1523	675
	25	807	1523	-458
Planted on 16-30 November; 18 000 plants ha^{-1}; 50 kg ha^{-1} N; weeding twice	75	2409	1748	1434
	50	1712	1748	514
	25	771	1748	-729
Planted on 1-15 December; 9 000 plants ha^{-1}; 35 kg ha^{-1} N; weeding once	75	1091	1350	91
	50	685	1350	-445
	25	402	1350	-819

Planted on 1-15 December; 9 000 plants ha^{-1}; 35 kg ha^{-1} N; weeding twice	75	1392	1374	464
	50	1001	1374	-52
	25	490	1374	-727
Planted on 1-15 December; 12 000 plants ha^{-1}; 35 kg ha^{-1} N; one times of weeding control	75	1194	1400	177
	50	744	1400	-416
	25	426	1400	-838
Planted on 1-15 December; 12 000 plants ha^{-1}; 35 kg ha^{-1} N; weeding twice	75	1633	1424	733
	50	1144	1424	87
	25	561	1424	-683
Planted on 1-15 December; 12 000 plants ha^{-1}; 50 kg ha^{-1} N; weeding twice	75	1571	1649	427
	50	1341	1649	123
	25	552	1649	-920
Planted on 1-15 December; 15 000 plants ha^{-1}; 35 kg ha^{-1} N; weeding twice	75	1699	1473	771
	50	1287	1473	227
	25	609	1473	-669
Planted on 1-15 December; 15 000 plants ha^{-1}; 50 kg ha^{-1} N; weeding twice	75	1677	1698	516
	50	1493	1698	273
	25	596	1698	-911
Planted on 1-15 December; 18 000 plants ha^{-1}; 35 kg ha^{-1} N; weeding twice	75	1759	1523	801
	50	1382	1523	303
	25	629	1523	-692
Planted on 1-15 December; 18 000 plants ha^{-1}; 50 kg ha^{-1} N; weeding twice	75	1722	1748	527
	50	1520	1748	260
	25	613	1748	-938
Planted on 1-15 December; 21 000 plants ha^{-1}; 35 kg ha^{-1} N; weeding twice	75	1758	1572	750
	50	1428	1572	314
	25	654	1572	-708

Table B16: Reference table for yield expectance, field costs and economic benefit under various sets of management practices during BN-NN rainfall conditions for Pioneer 3237

Management practices (For Pioneer 3237 cultivar)	Probability levels	Yield Expectance (kg ha^{-1})	Field Costs (Rand ha^{-1})	Economic benefit (Rand ha^{-1})
Planted on 1-15 November; 9 000 plants ha^{-1}; 35 kg ha^{-1} N; weeding once	75	1283	1421	273
	50	306	1421	-1016
	25	199	1421	-1158
Planted on 1-15 November; 9 000 plants ha^{-1}; 35 kg ha^{-1} N; weeding twice	75	1967	1445	1154
	50	1214	1445	158
	25	658	1445	-576
Planted on 1-15 November; 9 000 plants ha^{-1}; 50 kg ha^{-1} N; weeding thrice	75	2432	1694	1518
	50	1509	1694	299
	25	765	1694	-683
Planted on 1-15 November; 12 000 plants ha^{-1}; 35 kg ha^{-1} N; weeding twice	75	2040	1518	1177
	50	1288	1518	183
	25	750	1518	-527
Planted on 1-15 November; 12 000 plants ha^{-1}; 35 kg ha^{-1} N; weeding thrice	75	2001	1542	1101
	50	1454	1542	378
	25	751	1542	-550
Planted on 1-15 November; 12 000 plants ha^{-1}; 50 kg ha^{-1} N; weeding twice	75	1835	1743	681
	50	1367	1743	63
	25	559	1743	-1005
Planted on 1-15 November; 12 000 plants ha^{-1}; 50 kg ha^{-1} N; weeding thrice	75	2612	1767	1683
	50	1630	1767	386
	25	559	1767	-1029
Planted on 1-15 November; 12 000 plants ha^{-1}; 75 kg ha^{-1} N; weeding thrice	75	2638	2142	1343
	50	1598	2142	-32
	25	957	2142	-878
Planted on 1-15 November; 15 000 plants ha^{-1}; 35 kg ha^{-1} N; weeding twice	75	2066	1591	1138
	50	1327	1591	162
	25	817	1591	-511
Planted on 1-15 November; 15 000 plants ha^{-1}; 35 kg ha^{-1} N; weeding thrice	75	2042	1615	1081
	50	1490	1615	353
	25	813	1615	-542
Planted on 1-15 November; 15 000 plants ha^{-1}; 50 kg ha^{-1} N; weeding thrice	75	2137	1840	982
	50	1652	1840	341
	25	813	1840	-767
Planted on 1-15 November; 15 000 plants ha^{-1}; 75 kg ha^{-1} N; weeding thrice	75	2558	2216	1163
	50	1765	2216	116
	25	948	2216	-964

Planted on 1-15 November; 18 000 plants ha^{-1}; 35 kg ha^{-1} N; weeding twice	75	1345	1664	112
	50	909	1664	-463
	25	473	1664	-1040
Planted on 1-15 November; 18 000 plants ha^{-1}; 35 kg ha^{-1} N; weeding thrice	75	1534	1688	338
	50	1275	1688	-5
	25	778	1688	-661
Planted on 1-15 November; 18 000 plants ha^{-1}; 50 kg ha^{-1} N; weeding twice	75	2202	1889	1019
	50	1592	1889	214
	25	656	1889	-1023
Planted on 1-15 November; 18 000 plants ha^{-1}; 50 kg ha^{-1} N; weeding thrice	75	2135	1914	906
	50	1666	1914	287
	25	831	1914	-816
Planted on 1-15 November; 18 000 plants ha^{-1}; 75 kg ha^{-1} N; weeding thrice	75	3007	2289	1684
	50	1754	2289	29
	25	971	2289	-1005
Planted on 1-15 November; 21 000 plants ha^{-1}; 35 kg ha^{-1} N; weeding thrice	75	2125	1762	1046
	50	1513	1762	237
	25	815	1762	-685
Planted on 1-15 November; 21 000 plants ha^{-1}; 50 kg ha^{-1} N; weeding twice	75	2722	1963	1633
	50	1570	1963	111
	25	713	1963	-1021
Planted on 16-30 November; 9 000 plants ha^{-1}; 35 kg ha^{-1} N; weeding twice	75	1409	1445	417
	50	928	1445	-219
	25	346	1445	-987
Planted on 16-30 November; 9 000 plants ha^{-1}; 50 kg ha^{-1} N; weeding thrice	75	1629	1694	457
	50	1182	1694	-133
	25	387	1694	-1183
Planted on 16-30 November; 12 000 plants ha^{-1}; 35 kg ha^{-1} N; weeding thrice	75	1468	1542	397
	50	1127	1542	-54
	25	404	1542	-1008
Planted on 16-30 November; 12 000 plants ha^{-1}; 50 kg ha^{-1} N; weeding twice	75	1740	1743	555
	50	1108	1743	-280
	25	405	1743	-1209
Planted on 16-30 November; 12 000 plants ha^{-1}; 50 kg ha^{-1} N; weeding thrice	75	1794	1767	603
	50	1346	1767	11
	25	404	1767	-1233
Planted on 16-30 November; 12 000 plants ha^{-1}; 75 kg ha^{-1} N; weeding twice	75	1701	2118	129
	50	1113	2118	-649
	25	402	2118	-1587
Planted on 16-30 November; 12 000 plants ha^{-1}; 75 kg ha^{-1} N; weeding thrice	75	1861	2142	316
	50	1273	2142	-460
	25	402	2142	-1611
Planted on 16-30 November; 15 000 plants ha^{-1}; 35 kg ha^{-1} N; weeding twice	75	1475	1591	358
	50	1063	1591	-187
	25	404	1591	-1058
Planted on 16-30 November; 15 000 plants ha^{-1}; 35 kg ha^{-1} N; weeding thrice	75	1440	1615	287
	50	1160	1615	-83
	25	24	1615	-1584
Planted on 16-30 November; 15 000 plants ha^{-1}; 50 kg ha^{-1} N; weeding thrice	75	1817	1840	559
	50	1330	1840	-83
	25	402	1840	-1309
Planted on 16-30 November; 15 000 plants ha^{-1}; 75 kg ha^{-1} N; weeding thrice	75	2036	2216	474
	50	1300	2216	-498
	25	402	2216	-1685
Planted on 16-30 November; 18 000 plants ha^{-1}; 35 kg ha^{-1} N; weeding thrice	75	1580	1688	399
	50	1228	1688	-66
	25	387	1688	-1177
Planted on 16-30 November; 18 000 plants ha^{-1}; 50 kg ha^{-1} N; weeding twice	75	1679	1889	328
	50	1100	1889	-437
	25	383	1889	-1384
Planted on 16-30 November; 18 000 plants ha^{-1}; 50 kg ha^{-1} N; weeding thrice	75	1801	1914	466
	50	1328	1914	-160
	25	384	1914	-1407
Planted on 16-30 November; 18 000 plants ha^{-1}; 75 kg ha^{-1} N; weeding thrice	75	2056	2289	428
	50	1307	2289	-563
	25	386	2289	-1778

Table B17: Reference table for yield expectance, field costs and economic benefit under various sets of management practices during BN-BN rainfall conditions for PAN 6479

Management practices (For PAN 6479 cultivar)	Probability levels	Yield Expectance (kg ha^{-1})	Field Costs (Rand ha^{-1})	Economic benefit (Rand ha^{-1})
Planted on 1-15 November; 9 000 plants ha^{-1}; 35 kg ha^{-1} N; weeding once	75	1143	1350	159
	50	968	1350	-71
	25	295	1350	-960
Planted on 1-15 November; 9 000 plants ha^{-1}; 35 kg ha^{-1} N; weeding twice	75	1272	1374	306
	50	1025	1374	-20
	25	801	1374	-316
Planted on 1-15 November; 12 000 plants ha^{-1}; 35 kg ha^{-1} N; weeding once	75	1353	1400	388
	50	1126	1400	87
	25	320	1400	-976
Planted on 1-15 November; 12 000 plants ha^{-1}; 35 kg ha^{-1} N; weeding twice	75	1615	1424	709
	50	1128	1424	66
	25	958	1424	-159
Planted on 1-15 November; 15 000 plants ha^{-1}; 35 kg ha^{-1} N; weeding once	75	1385	1449	380
	50	1099	1449	2
	25	317	1449	-1031
Planted on 1-15 November; 15 000 plants ha^{-1}; 35 kg ha^{-1} N; weeding twice	75	1647	1473	703
	50	1167	1473	68
	25	898	1473	-287
Planted on 1-15 November; 18 000 plants ha^{-1}; 35 kg ha^{-1} N; weeding once	75	1416	1499	372
	50	1190	1499	74
	25	281	1499	-1128
Planted on 1-15 November; 18 000 plants ha^{-1}; 35 kg ha^{-1} N; weeding twice	75	1612	1523	606
	50	1221	1523	91
	25	904	1523	-329
Planted on 1-15 November; 21 000 plants ha^{-1}; 35 kg ha^{-1} N; weeding once	75	1402	1548	304
	50	1223	1548	68
	25	243	1548	-1227
Planted on 1-15 November; 21 000 plants ha^{-1}; 35 kg ha^{-1} N; weeding twice	75	1652	1572	609
	50	1286	1572	126
	25	898	1572	-386
Planted on 16-30 November; 9 000 plants ha^{-1}; 35 kg ha^{-1} N; weeding once	75	1094	1350	96
	50	779	1350	-322
	25	28	1350	-1313
Planted on 16-30 November; 9 000 plants ha^{-1}; 35 kg ha^{-1} N; weeding twice	75	1181	1374	186
	50	1001	1374	-52
	25	101	1374	-1241
Planted on 16-30 November; 12 000 plants ha^{-1}; 35 kg ha^{-1} N; weeding once	75	1116	1400	74
	50	740	1400	-422
	25	32	1400	-1357
Planted on 16-30 November; 12 000 plants ha^{-1}; 35 kg ha^{-1} N; weeding twice	75	1375	1424	393
	50	1030	1424	-64
	25	110	1424	-1279
Planted on 16-30 November; 15 000 plants ha^{-1}; 35 kg ha^{-1} N; weeding once	75	1024	1449	-97
	50	582	1449	-681
	25	34	1449	-1404
Planted on 16-30 November; 15 000 plants ha^{-1}; 35 kg ha^{-1} N; weeding twice	75	1452	1473	445
	50	1041	1473	-98
	25	132	1473	-1299
Planted on 16-30 November; 18 000 plants ha^{-1}; 35 kg ha^{-1} N; weeding once	75	990	1499	-192
	50	504	1499	-834
	25	35	1499	-1452
Planted on 16-30 November; 18 000 plants ha^{-1}; 35 kg ha^{-1} N; weeding twice	75	1361	1523	275
	50	993	1523	-211
	25	141	1523	-1337
Planted on 16-30 November; 21 000 plants ha^{-1}; 35 kg ha^{-1} N; weeding once	75	925	1407	-185
	50	438	1407	-829
	25	36	1407	-1359
Planted on 16-30 November; 21 000 plants ha^{-1}; 35 kg ha^{-1} N; weeding twice	75	1266	1431	242
	50	909	1431	-231
	25	140	1431	-1246
Planted on 1-15 December; 9 000 plants ha^{-1}; 35 kg ha^{-1} N; weeding once	75	740	1350	-373
	50	613	1350	-540
	25	33	1350	-1306

Planted on 1-15 December; 9 000 plants ha^{-1}; 35 kg ha^{-1} N; weeding twice	75	1083	1374	56
	50	802	1374	-315
	25	69	1374	-1284
Planted on 1-15 December; 12 000 plants ha^{-1}; 35 kg ha^{-1} N; weeding once	75	832	1400	-301
	50	515	1400	-719
	25	40	1400	-1347
Planted on 1-15 December; 12 000 plants ha^{-1}; 35 kg ha^{-1} N; weeding twice	75	1216	1424	182
	50	998	1424	-105
	25	128	1424	-1255
Planted on 16-30 November; 15 000 plants ha^{-1}; 35 kg ha^{-1} N; weeding once	75	838	1449	-343
	50	435	1449	-875
	25	42	1449	-1394
Planted on 1-15 December; 15 000 plants ha^{-1}; 35 kg ha^{-1} N; weeding twice	75	1344	1473	302
	50	1004	1473	-147
	25	132	1473	-1299
Planted on 1-15 December; 18 000 plants ha^{-1}; 35 kg ha^{-1} N; weeding once	75	966	1499	-223
	50	384	1499	-992
	25	68	1499	-1409
Planted on 1-15 December; 18 000 plants ha^{-1}; 35 kg ha^{-1} N; weeding twice	75	1420	1523	353
	50	920	1523	-307
	25	146	1523	-1330
Planted on 1-15 December; 21 000 plants ha^{-1}; 35 kg ha^{-1} N; weeding once	75	901	1548	-358
	50	423	1548	-990
	25	73	1548	-1452
Planted on 1-15 December; 21 000 plants ha^{-1}; 35 kg ha^{-1} N; weeding twice	75	1447	1572	339
	50	836	1572	-468
	25	147	1572	-1378

Table B18: Reference table for yield expectance, field costs and economic benefit under various sets of management practices during BN-BN rainfall conditions for Pioneer 3237

Management practices (For Pioneer 3237 cultivar)	Probability levels	Yield Expectance (kg ha^{-1})	Field Costs (Rand ha^{-1})	Economic benefit (Rand ha^{-1})
Planted on 1-15 November; 9 000 plants ha^{-1}; 35 kg ha^{-1} N; weeding once	75	1894	1421	1081
	50	1375	1421	396
	25	0	1421	-1421
Planted on 1-15 November; 9 000 plants ha^{-1}; 35 kg ha^{-1} N; weeding twice	75	2216	1445	1482
	50	1841	1445	987
	25	366	1445	-961
Planted on 1-15 November; 9 000 plants ha^{-1}; 50 kg ha^{-1} N; weeding once	75	1902	1646	867
	50	1244	1646	-3
	25	0	1646	-1646
Planted on 1-15 November; 9 000 plants ha^{-1}; 50 kg ha^{-1} N; weeding twice	75	2520	1670	1659
	50	792	1670	-625
	25	101	1670	-1537
Planted on 1-15 November; 12 000 plants ha^{-1}; 35 kg ha^{-1} N; weeding once	75	2032	1494	1190
	50	1418	1494	379
	25	0	1494	-1494
Planted on 1-15 November; 12 000 plants ha^{-1}; 35 kg ha^{-1} N; weeding twice	75	2225	1518	1421
	50	1982	1518	1100
	25	427	1518	-954
Planted on 1-15 November; 12 000 plants ha^{-1}; 50 kg ha^{-1} N; weeding twice	75	2681	1743	1798
	50	2120	1743	1057
	25	427	1743	-1179
Planted on 1-15 November; 15 000 plants ha^{-1}; 35 kg ha^{-1} N; weeding once	75	2143	1567	1264
	50	1448	1567	345
	25	0	1567	-1567
Planted on 1-15 November; 15 000 plants ha^{-1}; 35 kg ha^{-1} N; weeding twice	75	2291	1591	1435
	50	2053	1591	1121
	25	453	1591	-992
Planted on 1-15 November; 15 000 plants ha^{-1}; 50 kg ha^{-1} N; weeding twice	75	2481	1816	1461
	50	2035	1816	872
	25	455	1816	-1215
Planted on 1-15 November; 18 000 plants ha^{-1}; 35 kg ha^{-1} N; weeding once	75	1538	1640	392
	50	608	1640	-837
	25	0	1640	-1640
Planted on 1-15 November; 18 000 plants ha^{-1}; 50 kg ha^{-1} N; weeding once	75	2230	1865	1081
	50	1307	1865	-139
	25	0	1865	-1865

Planted on 1-15 November; 18 000 plants ha^{-1}; 50 kg ha^{-1} N; weeding twice	75	2370	1889	1241
	50	1982	1889	728
	25	479	1889	-1256
Planted on 1-15 November; 21 000 plants ha^{-1}; 35 kg ha^{-1} N; weeding once	75	2232	1713	1235
	50	1503	1713	272
	25	0	1713	-1713
Planted on 1-15 November; 21 000 plants ha^{-1}; 35 kg ha^{-1} N; weeding twice	75	2299	1738	1300
	50	1841	1738	695
	25	452	1738	-1141
Planted on 1-15 November; 21 000 plants ha^{-1}; 50 kg ha^{-1} N; weeding twice	75	2650	1963	1537
	50	2248	1963	1006
	25	458	1963	-1358
Planted on 16-30 November; 9 000 plants ha^{-1}; 35 kg ha^{-1} N; weeding once	75	1521	1421	588
	50	367	1421	-936
	25	0	1421	-1421
Planted on 16-30 November; 9 000 plants ha^{-1}; 35 kg ha^{-1} N; weeding twice	75	1942	1445	1121
	50	579	1445	-680
	25	0	1445	-1445
Planted on 16-30 November; 9 000 plants ha^{-1}; 50 kg ha^{-1} N; weeding once	75	1297	1646	68
	50	362	1646	-1168
	25	0	1646	-1646
Planted on 16-30 November; 9 000 plants ha^{-1}; 50 kg ha^{-1} N; weeding twice	75	1681	1670	551
	50	647	1670	-816
	25	0	1670	-1670
Planted on 16-30 November; 12 000 plants ha^{-1}; 35 kg ha^{-1} N; weeding once	75	1621	1494	648
	50	412	1494	-950
	25	0	1494	-1494
Planted on 16-30 November; 12 000 plants ha^{-1}; 35 kg ha^{-1} N; weeding twice	75	2008	1518	1134
	50	663	1518	-642
	25	0	1518	-1518
Planted on 16-30 November; 12 000 plants ha^{-1}; 50 kg ha^{-1} N; weeding twice	75	2421	1743	1455
	50	729	1743	-780
	25	0	1743	-1743
Planted on 16-30 November; 15 000 plants ha^{-1}; 35 kg ha^{-1} N; weeding once	75	1660	1567	626
	50	437	1567	-989
	25	0	1567	-1567
Planted on 16-30 November; 15 000 plants ha^{-1}; 35 kg ha^{-1} N; weeding twice	75	2046	1591	1111
	50	717	1591	-644
	25	0	1591	-1591
Planted on 16-30 November; 15 000 plants ha^{-1}; 50 kg ha^{-1} N; weeding twice	75	2426	1816	1388
	50	725	1816	-859
	25	0	1816	-1816
Planted on 16-30 November; 18 000 plants ha^{-1}; 35 kg ha^{-1} N; weeding once	75	1681	1640	580
	50	459	1640	-1034
	25	0	1640	-1640
Planted on 16-30 November; 18 000 plants ha^{-1}; 35 kg ha^{-1} N; weeding twice	75	2084	1664	1088
	50	753	1664	-669
	25	0	1664	-1664
Planted on 16-30 November; 21 000 plants ha^{-1}; 35 kg ha^{-1} N; weeding once	75	1700	1713	532
	50	386	1713	-1203
	25	0	1713	-1713
Planted on 16-30 November; 21 000 plants ha^{-1}; 35 kg ha^{-1} N; weeding twice	75	2166	1738	1124
	50	786	1738	-699
	25	0	1738	-1738