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Effect of summer fallow management on crop yield: Field experiment and simulation analysis

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ABSTRACT

Potential yield of a crop is limited by the factor which most restricts its productivity. In dryland cropping systems this factor is often the available soil water. Nitrogen fertiliser is also a high cost input in crop production systems. Conservation of these resources is essential to increase agricultural productivity and profitability. A field experiment and computer simulation modelling were conducted for the dryland farming system of south eastern Australia to investigate the effect of summer fallow management on growth and yield of canola (*Brassica napus* L.). A factorial experiment with two residual nitrogen levels and three residual soil water conditions was conducted. Soil water content and crop growth were monitored. At harvest, canola grain yield and above-ground biomass were measured. The biophysical model APSIM was used to analyse the effect of seasonal variation on crop yield by simulating canola grain yield at different residual water and nitrogen levels. The field experiment and simulation modelling indicated that in seasons with high in-crop rainfall, high residual soil water does not increase crop yield. However, residual nitrogen increases crop yield if in-crop rainfall is high. Irrespective of the in-crop rainfall, controlling summer weeds increases crop yield due to residual mineral N and/or residual soil water.

1. Introduction

Water and nitrogen fertiliser are two of the most important inputs that need to be available in sufficient quantities for a crop to reach its potential yield. High yield is obtained when both factors are not limited (Moore and Hunt, 2012). Crop yield and the resulting return for these inputs is uncertain when rainfall variability is high as is often the case in the dryland/rainfed farming system (Angus, 2001). Several studies have shown that fallow period management, such as weed control aimed at reducing transpiration and N uptake and stubble retention to reduce evaporation and runoff, increase soil water storage and nitrogen for the following season crop. Residual water from the summer fallow period is particularly important in regions where winter crop production often depends on the amount of residual soil moisture (Angus et al., 1980). In the region where the experiment in this study was conducted, Zeleke (2017) showed that summer weed control increased residual soil water and residual soil nitrogen by 64 mm and 60 kg ha^{-1}, respectively. Lilley and Kirkegaard (2007) used simulation modelling to show that control of summer weeds would increase subsequent wheat yield by 6–20%. Weed control enables soil water storage in the deeper soil profile which can be accessed when the crop water demand and yield response to water is high (Moore and Hunt, 2012) while residual soil water at shallow depths using stubble cover enables early sowing of long season cultivars (Kirkegaard and Hunt, 2010). The conversion of stored soil water into grain yield depends on the amount and distribution of rainfall during the crop growing season. In studies conducted in this region, Kirkegaard et al. (2007b) generated a range of starting soil water contents and observed that any additional stored soil water was converted to 18 kg ha^{-1} mm^{-1} and 29 kg ha^{-1} mm^{-1} depending on the season. However, from these studies it was not clear whether the increase in yield was due to conserved water or conserved nitrogen or both. The objective of this study is to investigate the effect of residual soil water and residual nitrogen on canola (*Brassica napus* L.) yield in south eastern NSW, a transition zone from the summer-dominant rainfall northern regions to the winter-dominant rainfall southern regions of Australia using field experimentation and simulation modelling.

2. Materials and method

2.1. Field experiment

A field experiment to evaluate the effect of summer fallow management on soil water and nitrogen conservation and crop yield was

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Table 1
Hydrologic properties of the Red Kandosol soil at Wagga Wagga, NSW Australia (APSoil, 2013).

Soil depth (cm)	Bulk density (g cm^{-3})	Wilting point (LL15)[a] (cm^3 cm^{-3})	Field capacity (DUL)[b](cm^3 cm^{-3})	Saturation moisture content (cm^3 cm^{-3})
0–15	1.48	0.11	0.29	0.35
15–30	1.50	0.13	0.27	0.34
30–45	1.45	0.15	0.25	0.32
45–60	1.37	0.15	0.28	0.36
60–90	1.43	0.15	0.29	0.35
90–120	1.55	0.15	0.31	0.34

[a] LL15 is the soil water content at 15 bar pressure which is the lower limit of the plant available water.
[b] DUL (drainable upper limit) is the soil water content at field capacity.

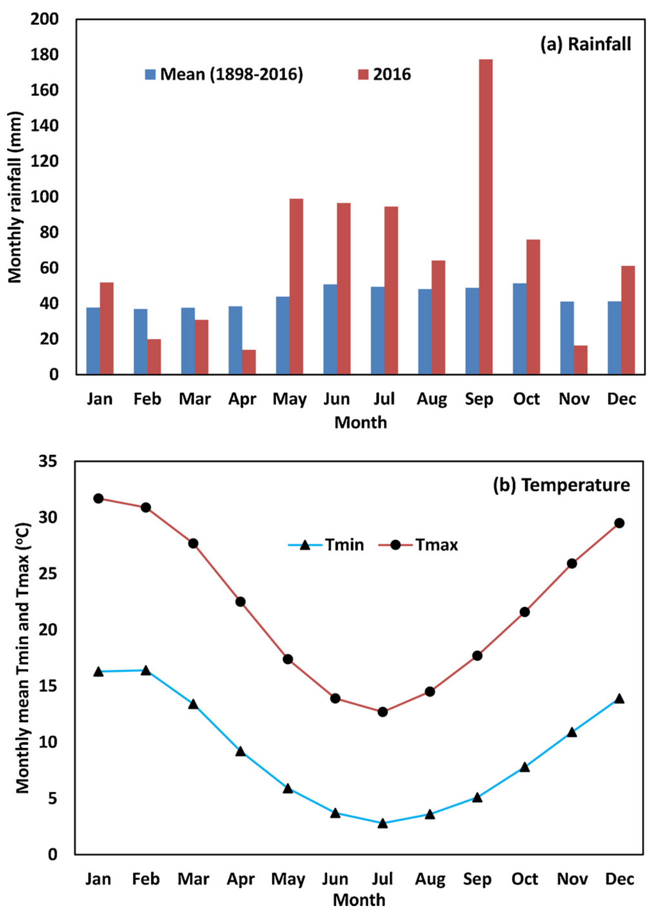

Fig. 1. (a) Mean monthly rainfall (1898–2016) and monthly rainfall for 2016; (b) Mean monthly minimum (Tmin) and maximum temperature (Tmax) at Wagga Wagga, NSW Australia.

conducted at Wagga Wagga, NSW Australia in the 2015-16 summer fallow period and 2016 winter cropping season. There were 24 experimental plots, 5 m long and 1.8 m wide, with 0.5 m wide access path between the plots. Between the experimental plots, there are buffer plots of the same size and treated similarly to the adjacent experimental plots. The experimental plots were fitted with drip irrigation system. Neutron probe access tubes were installed in each plot for soil water content measurement. Neutron probe calibrated at the site was used to monitor soil moisture at 0.15, 0.30, 0.45, 0.60, 0.90, 1.20 m depths; separate calibration was used for the top 30 cm depth. The soil of the experimental site is a sandy clay loam Red Kandosol with its hydrologic characteristics as shown in Table 1 (APSoil, 2013). The monthly rainfall, monthly mean minimum and maximum temperature is presented in Fig. 1. There was 52% more annual rainfall and 87% more in-season (May–November) rainfall in 2016 compared to the long term average. The 2015–2016 summer fallow period treatments, weed/no weed and stubble/no stubble, created different residual water and residual nitrogen levels at the end of the fallow period (Zeleke, 2017). These residual water and nitrogen levels helped to formulate the treatments of this study: the three sowing-time residual soil water contents in 0–1.2 m soil depth: 0.214 (low), 0.251 (medium) and 0.279 (high) cm^3 cm^{-3} and the two residual nitrogen levels in 0–0.6 m soil depth, 39 kg N ha^{-1} (low) and 98 kg N ha^{-1} (high), respectively. Canola (cv. *Monty* L.) was sown on 28 April 2016 and harvested on 7 November 2016. The sowing rate was for a target plant population of 80 plants m^{-2}. Each plot had six rows of canola at 25 cm spacing. In order to investigate the contribution of residual water, residual nitrogen and their interaction on crop yield, a factorial experiment was conducted with residual nitrogen as the main plot and residual soil water content as sub-plot with three replications. All the experimental plots received nitrogen fertiliser at the time of sowing (46 kg N ha^{-1}) and two months after sowing (46 kg N ha^{-1}).

The crop green canopy cover was measured at about monthly interval using a handheld device GreenSeeker® (NTech Industries Inc., Ukiah, CA, USA) which measures normalized difference vegetation index (NDVI). NDVI is an accurate estimation of vegetation fraction (Gitelson, 2013). As a result NDVI was used as a proxy for green canopy cover. Water requirement of canola has already been determined at this site (Zeleke and Wade, 2011). During the growing season, above-ground dry matter was measured by destructive sampling of five plants per plot from the buffer plots treated similarly to the adjacent experimental plots. At harvest, the above-ground dry matter and grain yield was measured from one meter length of the internal four rows of each plot. Statistical analysis was done using the R program (R Development Core Team, 2016).

2.2. Simulation

The effect of residual soil water and residual nitrogen on canola yield under different seasonal climatic conditions was simulated using APSIM, a dynamic daily time step biophysical model that links biophysical (crop, soil, climate) and management modules to simulate agricultural systems (Holzworth et al., 2014). The modules are: crop growth, development and yield modules, soil N and organic matter dynamics module, soil water dynamics module, and stubble management module. APSIM has been extensively evaluated and applied in diverse cropping systems of Australia and other countries (Holzworth et al., 2014). APSIM has been tested in the study area for canola yield and soil water prediction (Zeleke et al., 2014b).

In this study APSIM was used to simulate canola grain yield under different residual soil water and residual nitrogen conditions as per the values obtained in the experimental. Two initial soil nitrogen levels were used for the simulation, one for the condition where nitrogen is depleted by the weed during the fallow period (NL) and the other for conditions where weed was controlled during the fallow period resulting in higher nitrogen level in the soil (NH). This was factored with three residual soil water conditions: low (ML), medium (MM), and high (MH), similar values to the ones obtained from the experiment. Hence, six combination of treatments were simulated: NL-ML, NL-MM, NL-MH, NH-ML, NH-MM, and NH-MH. The SILO patched point climate dataset for Wagga Wagga Agricultural station was used (https://legacy.longpaddock.qld.gov.au/silo/). SILO is a climate database which contains Australian climate data from 1889 to current. It provided historical daily datasets for a range of climate variables, including rainfall. Canola (*cv. Monty* L.) was 'sown' on 27 April 2016. Nitrogen fertiliser was 'applied' at sowing (50 kg N ha^{-1}) and two months after sowing (50 kg N ha^{-1}) as urea_N.