Alternative Crop Management Methods to Increase Crop Productivity and Farmer Utility

by N. Thomas

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Highlights

- Calibrating fertiliser application to forecast precipitation increases crop productivity.
- Hydropriming seeds and livestock grazing crop residue are complimentary management methods to increase fertiliser efficacy.
- Hydropriming increases yield and farmer utility by up to 32% in low rainfall dryland crop production.

Keywords

Fertilizer, crop production, hydropriming seeds, productivity, land management, low rainfall, dryland agriculture

JEL Codes

Q150, Q180, Q240, Q560

Abstract

Fertiliser and seasonal precipitation in dryland crop production is critical for maximising yield. Management planning uses climatic forecasts to determine optimal fertiliser application times and amounts. Climatic variation is intensifying, increasing dryland crop yield variability. Low rainfall dryland crop production globally is vulnerable to climatic variability. No work has considered hydropriming seeds with liquid fertiliser and grazing livestock on post-harvest residue to increase yield and reduce the impact of unexpected rainfall variation on crop productivity.

Livestock grazing crop residue during fallowing is common but the impact on crop productivity has not been evaluated. The benefits of hydropriming seeds with fertiliser has not been considered in crop productivity analysis before. The yield and farmer utility will be evaluated for a mixed land use farm in Wagga Wagga, New South Wales, Australia characteristic of low rainfall dryland crop producing regions globally.

Crop modelling software will model crop yield for the period 1990 – 2015, modelling a control scenario using existing management practices. Alternative fertiliser application amounts and times will be modelled with hydropriming and livestock grazing post harvest crop residue. Net farmer utility will be calculated with results used to evaluate the optimal fertiliser and crop residue management strategies with forecast precipitation.

On average wheat yield increases by 15.3%, with farmer utility increasing by 10% using varied fertiliser management strategies. Calibrating fertiliser and management strategies to seasonal precipitation forecasts, increases barley yield by up to 32%, with farmer utility increasing by 55%. Hydropriming seeds increases yield and economic returns in low rainfall seasons for wheat and barley, with increased yield in high rainfall seasons for wheat, barley, canola and field peas. Hydropriming provides dryland crop producers in low rainfall regions with simple strategies to increase productivity, with previously unconsidered management techniques.

Introduction

Cereal crops provide 60% of global food consumption, with dryland crop production using 80% of the cropped land area globally, yet produces only 55 – 60% of total cereal consumption (Alexandratos and Bruinsma, 2012). Fertiliser inputs are used to increase crop productivity and yield, however, existing management practices are inefficient with up to 45% of fertilisers applied unused in crop production (Tilman, et al., 2002). This report investigates two management methods to improve dryland crop productivity and farmer utility.

Australian farmers typical of low rainfall crop producers globally face significant seasonal rainfall variability impacting crop productivity and fertiliser input efficiency. Utilising seasonal forecasts produced by the Australian Bureau of Meteorology (BoM) can reduce management risks associated with precipitation variation in low rainfall dryland crop production (Brown, et al., 2018). Using seasonal forecasts to make *ex ante* crop production management decisions is a common strategy amongst farmers and has been applied previously to crop production fertiliser application rates (Asseng, et al., 2012, Hunt, 2021).

Rainfall in dryland crop production is the principal method for mobilising fertiliser nutrients into the soil profile, moving the nutrients towards the root system for use by crops. Seasonal precipitation rates impact the delivery of fertiliser nutrients into crop root zones. Below average annual precipitation reduces nutrient mobilisation into soils, subsequent crop nutrient uptake and growth rates. Above average annual precipitation increases soil nutrient leaching into subsoils where crop root systems are unable to access nutrients, reducing crop productivity (Zou, et al., 2015). Techniques to decrease soil nutrient flow variability and increase crop nutrient uptake require investigation to increase fertiliser input efficiency and crop productivity whilst providing farmer utility to famers.

Alternative methods of applying fertiliser and the impact on yield have been investigated, as has the timing of fertiliser applications to overcome the impact of reduced seasonal rainfall on fertiliser nutrient delivery to crops. Smaller, repeat applications of fertiliser over the crop growth period to increase productivity compared to a single application a sowing have been evaluated, however the net economic impact of smaller repeat applications has not been investigated (van Rees, et al., 2014). One fertiliser application method previously unconsidered in crop productivity analysis is hydropriming seeds using liquid fertiliser. (Hoben, et al., 2011, Lassaletta, 2014, Stoorvogel, et al., 2004, Van Drecht, et al., 2003, Warrender, et al., 2010).

Hydropriming involves soaking seeds in liquid fertiliser prior to sowing, delivering all the necessary nutrients for early plant growth to the seed. Hydropriming with liquid fertiliser increases crop germination rates by up to 11 % and early growth rates between 6 – 23% (Ali, et al., 2018, Di Girolamo and Barbanti, 2012, Farooq, et al., 2019, Jisha, et al., 2013). Previous works evaluating fertiliser application with climatic variation have not considered the yield benefits of hydropriming (Asseng, et al., 2012, van Rees, et al., 2014). The net economic benefit of hydropriming seeds, optimising yield and fertiliser management practice with climatic variation has not been investigated.

A common management practice to increase crop productivity is retaining prior crop harvest residue *in situ* over summer fallowing to mitigate the impact of hot dry summers on soil water content and reduce soil erosion (Dickson, 2020, Midwood and Birbeck, 2011). An alternative fallowing management practice is grazing livestock on crop residue, depositing nitrogen rich manure (Frischke, 2017). Mixed farm enterprises can rotate existing livestock assets grazed on other areas of the property onto crop residue. The impact of livestock grazing crop residue has been analysed to determine the economic impact for livestock production and soil carbon creation; but has not considered the impact on crop productivity (Rakkar and Blanco-Canqui, 2018).

Methodology

Study Area

Modelling uses a representative mixed land use farm in Wagga Wagga, New South Wales, growing a single crop annually over the period 1990 – 2015. The region was selected as representative of low rainfall dryland climatic conditions globally because of readily available, reliable climatic and soil data. Soil properties for the representative site were taken from the national soil database, ApSoil (https://www.apsim.info/apsim-model/apsoil/).

Site Climatology

Wagga Wagga has a temperate climate with hot summers and overnight frosts occurring in winter, with an average annual temperature of 15.8°C and annual rainfall of 569.4mm evenly spread throughout the year. Annual rainfall varies depending on global weather phenomenon such as the El Nino Southern Oscillation and Interdecadal Pacific Oscillation, resulting in abnormal annual precipitation with droughts and high rainfall seasons common (BOM, 2020, Western, et al., 2018).

Table 1: Annual Wagga Wagga, NSW, Rainfall Occurrence 1990 - 2015

Annual Rainfall	Definition	Occurrence in Period
Average rainfall	*within 20% of average annual rainfall*	*40%*
High Rainfall	*20% or greater than average*	*28%*
Low Rainfall (drought)	*20% or less than average*	*32%*

Source: (BOM, 2020)

Market Prices

Australian Bureau of Agricultural and Resource Economic Sciences (ABARES) data is used for grain market prices, using average regional farmgate receipts received in the modelling period for grains sold in 2020 prices per tonne (Table 2) (ABARES, 2020). Net profit is derived using regional crop receipts per tonne and costs data derived from the ABARES database for the New South Wales (NSW), Australia, Riverina Region and New South Wales Government Department of Primary Industries, Crop Production Budgeted Cost Data in 2020 prices (DPI, 2013). Cashflows are discounted using a discount rate of 5%, selected using the average national long term discount rate for the period (R.B.A, 2020).

The fertiliser price is derived from The World Bank Commodities Price Data (Bank, 2020, Wright, 2012). Labour and machinery costs used in fertiliser application are derived from NSW Department of Primary Industries Dryland Production Costs (DPI, 2013). Fertiliser application costs considered in marginal fertiliser application include: variable costs for operating a tractor and includes fuel, oil, filters, tyres, batteries, repairs and labour. Hydropriming of seeds uses an inconsequential amount of granular fertiliser dissolved in a bucket of water, with a cost of <$5.00 for 50 litres of liquid fertiliser used to hydroprime up to 3,000 seeds and is not considered in this analysis. Livestock are pre-existing assets with all livestock production costs and direct farmer utility to livestock from grazing crop residue ignored in this analysis.

Table 2: Crop Production Economic Data

Production Cost	**Wheat**	**Barley**	**Canola**	**Field Pea**
Weed control	66.69	71.93	46.14	107.77
Nitrogen fertiliser after canola	82.50	61.50	125.24	0.00
Sowing	58.40	66.05	56.00	65.76
Pest & disease control	17.08	0.00	75.61	30.25
Cultivation	0.00	0.00	97.02	0.00
Fertiliser	113.50	103.00	103.00	61.35
Contract harvest	63.60	68.40	60.00	57.19
Crop levies	10.27	13.97	15.42	4.68
Crop insurance	20.64	15.50	41.26	17.43
Total Cost ($ per ha)	**432.68**	**400.35**	**619.69**	**344.44**
Revenue ($ per ton)	**269.01**	**200.21**	**569.55**	**294.73**

Source: (ABARES, 2019, ABARES, 2020)

APSIM

Investigation and evaluation of alternative fertiliser management processes requires the use of crop modelling software capable of crop growth processes within the software being calibrated for the effects of hydropriming. The Agricultural Production Systems Simulation (APSIM) software was developed by the Commonwealth Scientific and Industrial Research Organisation (CSIRO) in Australia (Holzworth, et al., 2014, McCown, et al., 1996). It contains submodules for soil, crop growth, plant nutrient uptake and growth, water flows and nutrient movement, calibrated to user requirements for crop growth simulation.

APSIM has been utilised with numerous economic and physiological modelling research projects since its inception e.g. (Robertson and Lilley, 2016, Scanlan, et al., 2015, Thorburn, et al., 2001, Zheng, et al., 2015). The APSIMNextGen version is used in modelling to simulate daily crop growth and produce seasonal yield data. Individual crop files within the software will be varied to account for seed hydropriming impact on growth processes.

Initial Conditions

The soil water capacity is set to 70% of total soil water holding capacity for the APSIM model initialisation, evenly distributed. The soil carbon and nitrogen content are left unchanged from data inputted from ApSoil. Regional field data is used to calibrate crop root parameters and the maximum crop soil water extraction rate to simulate crop growth accurately (Holzworth, et al., 2014, Keating, et al., 2003).

Crop and agronomic parameters

The control fertiliser modelling scenario is 120kg of fertiliser applied at sowing, using a common crop rotation sequence for the region; wheat, canola, field peas, wheat, barley (ABARES, 2020; Cameron et al., 2015). Crops are sown during the period 01 March – 30 June when soil water equals or is greater than 15mm, or the end of the period if not sown during the period.

Fallowing Practices

Two alternative fallowing practices are investigated, traditional fallowing with crop residue retained on the soil surface over summer and the alternative, 64 kg weaner merino sheep grazing crop residue during summer fallowing. The sheep are rotated onto crop stubble during fallowing with urine and manure inputs deposited onto the soil surface. Livestock are grazed until surface residue is reduced to 50% of the original cover then removed. It is assumed the farmer has portable water troughs for sheep hydration as pre-existing assets. All fertiliser scenarios are modelled with both fallowing regimes, using both hydropriming and the control treatments for each fallowing scenario.

Hydropriming

Seeds are hydroprimed through immersion, the seeds are placed in a bucket with liquid fertiliser for 5 – 48 hours depending on the crop, before being drained, spread out on a hard surface and air dried. Liquid fertiliser is created by dissolving 2.5kg of commonly used Diammonium phosphate (DAP) fertiliser in 50 litres of water. Seeds are stored until soil and climatic conditions are suitable for sowing (Farooq, et al., 2019). Crop daily root and shoot growth rates used in hydropriming are based on the works of Holzworth, et al. (2014), Robertson and Lilley (2016), Zheng, et al. (2015).

Root system mass is calculated daily in APSIM dependent on daily root growth, ΔD_r, (1), which utilises phenological stage dependent root growth depth rates, R_r, (Table 3), a temperature factor, f_{rt}, soil water factor, f_{rw}, available soil water factor, f_{rwa}, and root exploration factor, B_i, where *i* is the soil layer where the roots are growing. Hydro primed seeds have increased root development during phenological germination to emergences stages. Root growth rates (R_r) increase with hydropriming compared to crops in control treatments, using results observed in field trials for individual crops (Table 3), with all other variables unchanged (Farooq, et al., 2006, Farooq, et al., 2020, Kaur, et al., 2002, Khazaei, et al., 2009).

$$\Delta D_r = R_r \times f_{rt} \times \min(f_{rw}, f_{rwa}) \times B_i \tag{1}$$

Table 3: Root Growth Rates

Root growth rate (R_r)	*(mm/d^{-1})*			
	Canola	*Wheat*	*Barley*	*Field Pea*
Control	5.0	5.0	5.0	3.0
Hydropriming	5.42156	5.5645	5.5645	9.5165
Shoot growth rate (r_ϵ)				
	Canola	*Wheat*	*Barley*	*Field Pea*
Control	5.0	1.5	1.0	5.0
Hydropriming	6.11876	1.603398	1.0689	11.53846

Source: (APSIM, 2019, Farooq, et al., 2006, Farooq, et al., 2020, Farooq, et al., 2019, Holzworth, et al., 2014, Jisha, et al., 2013, Kaur, et al., 2002, Khazaei, et al., 2009, Mahawar, et al., 2016, Patra, et al., 2016, Robertson and Lilley, 2016, Zheng, et al., 2015)

After germination shoot development is calibrated in APSIM software using predetermined crop specific shoot elongation rates, the depth of the seed at sowing and thermal targets using Probert, et al. (1998), Zheng, et al. (2015). Hydropriming increases shoot development rates during the emergence phenological stage, influenced by the depth of the seed placement at sowing, D_{seed}. The initial shoot elongation rate is slow, T_{lag}, before a linear growth period, using a relationship between the crop specific rate of shoot elongation, r_ϵ, (Table 3) and sowing depth. With hydropriming, r_ϵ is increased by rates determined from field trials (Farooq, et al., 2006, Farooq, et al., 2020, Kaur, et al., 2002, Khazaei, et al., 2009). Hydropriming decreases the period between germination to emergence, T_{emer}, (2) compared to unprimed seeds and is calculated by:

$$T_{emer} = T_{lag} + r_\epsilon D_{seed} \tag{2}$$

Fertiliser scenarios

Crop modelling will be completed with 17 different fertiliser application scenarios. Four fertiliser treatments are evaluated using conventional unmodified software and with APSIM software calibrated for seed hydropriming.

Table 4: Fertiliser Modelling Treatments

	Treatment
1	Control with traditional fallow
2	Control with livestock grazing fallowing residue
3	Hydropriming with traditional fallow
4	Hydropriming with livestock grazing fallowing

APSIM software has a function for user calibration of fertiliser application at set times, allowing for homogeneity of application across years modelled. Five different application times will be considered: after the prior crop is harvested, at crop sowing, a month after crop sowing, 3 months after sowing the crop and 4 months after sowing. All fertiliser application treatments are modelled with control and hydropriming scenarios. Varied fertiliser application quantities will be modelled using the four fertiliser treatments. The application quantity will be decreased by 20%, increased by 20% or 40%, to determine yield variation from the control, modelled using the control and hydropriming management methods with traditional fallowing and livestock grazing crop residue. Yield results will be utilised to determine the optimal fertiliser treatment and farmer utility, using average rainfall. Yield results will then be segmented by seasonal rainfall and the optimal management strategy selected for low, average and high seasonal rainfall.

Crop Production Economic Function

Crop production and management decisions are assumed to be undertaken *ex ante* in each production season involving risk with unknown output and prices. Farmers make decisions on production processes and inputs used prior to actual crop yields becoming known and are based on planned yield rather than observed yields implied by an *ex post* cost function with no yield uncertainty (Pope and Chavas, 1994). When making *ex ante* production decisions farmers are assumed to seek to minimise the variable cost of production in terms of their planned output and yield levels (Lafrance, et al., 2011).

The crop production model is based on the *ex ante joint production system* of LaFrance and Pope (2010) with variable inputs, quasi-fixed inputs, soil nutrients as state variables, output and output price risk. Let $\boldsymbol{w} \in \boldsymbol{W} \subset \mathbb{R}_{+}^{n_x}$ be an n_x −vector of variable input prices, let $\boldsymbol{x} \in \boldsymbol{X} \subset \mathbb{R}_{+}^{n_x}$ be an n_x −vector of variable inputs, let $\bar{\boldsymbol{y}} \in \boldsymbol{Y} \subset \mathbb{R}_{+}^{n_y}$ be an n_y −vector of planned crop output levels, let $\boldsymbol{z} \in \boldsymbol{Z} \subset \mathbb{R}_{+}^{n_z}$ be an n_z −vector of quasi-fixed inputs. The variable input demand functions are defined by:

$$\boldsymbol{x}(\boldsymbol{w}, \bar{\boldsymbol{y}}, \boldsymbol{x}, \boldsymbol{z}) = argmin\{\boldsymbol{w}'\boldsymbol{x} : F(\boldsymbol{x}, \bar{\boldsymbol{y}}, \boldsymbol{z}) \leq 0\}, \tag{3}$$

Where $F: \mathbb{R}_{+}^{n_x} \times \mathbb{R}_{+}^{n_y} \times \mathbb{R}_{+}^{n_z} \rightarrow \mathbb{R}_{-}$ is a joint production transformation function that identifies how variable inputs are converted to planned outputs conditional on quasi-fixed inputs. This function in decreasing in the inputs, $(\boldsymbol{x}, \boldsymbol{z})$, increasing in the planned outputs, $\bar{\boldsymbol{y}}$, and jointly convex in all inputs and planned outputs, $(\boldsymbol{x}, \bar{\boldsymbol{y}}, \boldsymbol{z})$. In each period, the farmer is assumed to minimise the variable cost of production for planned outputs given quasi-fixed inputs,

$$c(\boldsymbol{w}, \bar{\boldsymbol{y}}, \boldsymbol{z}) = min\{\boldsymbol{w}'\boldsymbol{x} : F(\boldsymbol{x}, \bar{\boldsymbol{y}}, \boldsymbol{z}) \leq 0\} \tag{4}$$

Supply shocks are captured as a function of planned outputs, quasi-fixed inputs and an n_y − vector of error terms, $\varepsilon \in \mathbb{R}^{n_y}$,

$$y = \bar{\boldsymbol{y}} + h(\bar{\boldsymbol{y}}, z, \varepsilon), \quad E[h(\bar{\boldsymbol{y}}, z, \varepsilon) | x, \bar{\boldsymbol{y}}, z] = 0_{n_y} \tag{5}$$

In the production model applied in this study, the *conditional variable input demands* are assumed to be functions of variable input prices, quasi-fixed inputs and variable costs of planned production:

$$\boldsymbol{x}(\boldsymbol{w}, \bar{\boldsymbol{y}}, \boldsymbol{z}) = \widetilde{\boldsymbol{x}}\big(\boldsymbol{w}, \boldsymbol{z}, c(\boldsymbol{w}, \bar{\boldsymbol{y}}, \boldsymbol{z})\big). \tag{6}$$

Following LaFrance and Pope (2010), variable inputs are weakly separable from planned outputs in the variable cost function. To be consistent with regional cost data obtained from the New South Wales Department of Primary Industries for regional crop production (DPI, 2013), it also is assumed that all capital expenditures on machinery, shedding, etc. are incurred regardless of crop selection decisions. These costs are aggregated and included as farm production capital. For clarity, it is assumed that production costs that include site preparation, sowing, pest and disease management remain fixed throughout the current crop production period and are predetermined from variable input costs. The cost measures use 2020 prices and include fertiliser, fungicides, pesticides, labour, weed control, site preparation, variable machinery costs (fuel, filters, tyres and repairs, etc.), seeds, sowing, harvest, crop insurance, contract and levy costs. All variable costs are calibrated to individual crop production management requirements (see Table 2).

It is assumed throughout that only one crop is grown on a given plot of land in each production period. These production periods are taken to be annual in the study, and each crop has its own production function. Crop selection for the period $i = 1, \cdots, n_y$, is determined *ex ante* with the planned yield in a given production period, $\bar{y}_i(t)$, subject to the climate and variable inputs, with forecast climatic conditions known but actual climatic conditions over the cropping period unknown at the start of the modelling period.

The objective of the farmer is to maximise net returns from crop production. The returns from livestock production are not central to crop rotation decision making, so are not considered in this analysis. Expected output for a crop, $y_{i,t}$, is the *ex ante* planned yield plus the yield variation, $\varepsilon_{i,t+1}$, capturing the impact of climate on expected yield, realised *ex post.* Expected output is derived using APSIM crop modelling software, calibrated to site soil, climatic conditions and fertiliser inputs.

$$y_{i,t+1} = \bar{y}_{i,t}\left(1 + \varepsilon_{i,t+1}\right), \ \ i = 1, 2, \ldots.n_y \tag{7}$$

The farmer seeks to maximise the returns and indirect farmer utility for a selected crop for the production period by choosing the conditional variable inputs that maximise yield and farmer returns.

$$v(y, \boldsymbol{x}) = \max_{0 > y \geq \bar{y}} \int_0^T e^{-\delta t}\{\left(p_{i,t+1} y_{i,t+1}\right) - (\boldsymbol{w}_{i,t} \boldsymbol{x}_{\boldsymbol{i},\boldsymbol{t}}(\boldsymbol{w}, \bar{\boldsymbol{y}}, \boldsymbol{z}))^{1+\delta}\} \tag{8}$$

For an alternative fertiliser strategy or residue management practice to be implemented the indirect utility derived from the production process must exceed the control.

$$v'(y, \boldsymbol{x}) > \ v(y, \boldsymbol{x}) \tag{9}$$

The decision rule for farmers to implement the alternative production process utilises the marginal economic benefit of any variation in fertiliser application or management treatment. The marginal utility flows derived from an alternative management method need to exceed the marginal economic cost of implementation:

$$p_{i,t+1} \cdot {y'}_{i,t+1} > \ \left(\boldsymbol{w}_{i,t} \boldsymbol{x}'_{\boldsymbol{i},\boldsymbol{t}}\right)^{1+\delta} \tag{10}$$

Results

When the optimal residue management scenario and fertiliser application treatment is selected for a crop calibrated using long term average annual rainfall, yield increases between 0.1 – 11.2% over the control (Figure 2).

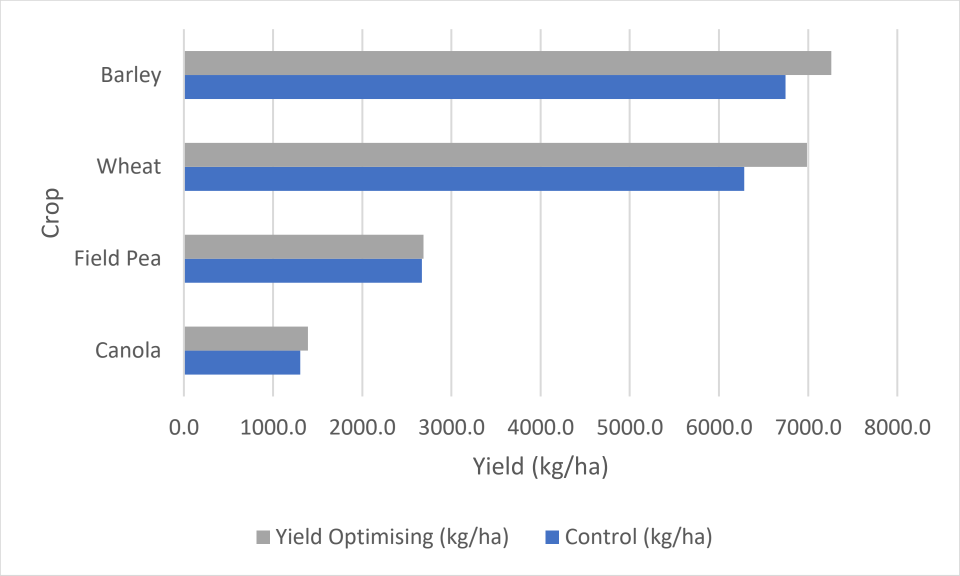

Figure 2: Yield Optimised Average Crop Yield

The largest yield increases occur in wheat with livestock grazing residue during summer fallows annually and a single application of 168kg of nitrogen one month after sowing, increasing wheat yield by 11.2% (Table 5). Field Peas have the lowest optimal yield response (0.1%), obtained with an application of 142kg of nitrogen at sowing and livestock grazing residue during summer fallowing. Canola yield increases by 6.4% compared to the control when using hydropriming, with 60kg of fertiliser applied during fallowing after the prior crop harvest and again at sowing. Average barley yield increased by 7.6% with hydropriming and a single application of 168kg of fertiliser applied a month after sowing.

Table 5: Yield Optimising Fertiliser Scenarios

Optimal Scenarios	***Fertiliser Application***	***Treatment***	***Change from Control to Optimising (%)***
Canola	2 *60kg, PH, S	Hydropriming livestock fallowing	6.4
Field Pea	96 kg DS	Control traditional fallowing	0.1
Wheat	168 kg DS	Control livestock fallowing	11.2
Barley	168 kg DS	Hydropriming traditional fallowing	7.6

Fertiliser Application Time: S = Sowing, DS = Delayed Sowing, PH = After prior crop harvest, DG= 3 months after sowing, DG1= 4 months after sowing

The optimal management strategies with average rainfall used in seasonal decision making has little impact on farmer indirect utility. Returns from crop production are maintained or slightly increased in the case of canola and wheat as illustrated in Figure 3.

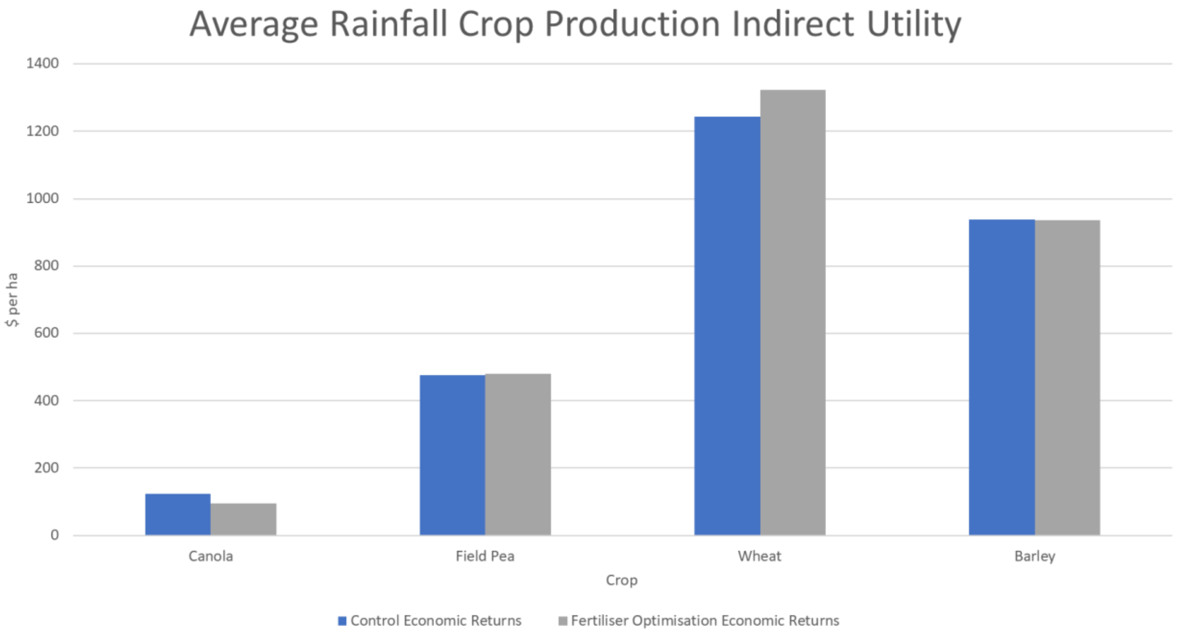

Figure 3: Average Rainfall Optimised Indirect Utility

Yield results and the optimal fertiliser management strategy obtained using long term average annual rainfall does not allow for varied management strategies calibrated to forecast seasonal precipitation. When disaggregated by annual precipitation, the optimal fertiliser management strategies to increase crop productivity varies (Table 6).

Table 6: Rainfall Disaggregated Optimal Fertiliser Management Strategy

Annual Rainfall	**Fertiliser Application**	**Treatment**	**Yield Variation (%)**
Canola			
Low Rainfall	168kg S	Control livestock fallowing	16.6
Average Rainfall	2 * 48kg, DS, DSG1	Hydropriming	1.0
High Rainfall	2 * 48kg, DS, DSG1	Hydropriming	5.4
Wheat			
Low Rainfall	168kg DS	Hydropriming	4.9
Average Rainfall	168kg DS	Control livestock fallowing	11.7
High Rainfall	168kg DS	Hydropriming livestock fallowing	4.8
Barley			
Low Rainfall	142kg, S	Hydropriming	0.1
Average Rainfall	168kg DS	Control	2.3
High Rainfall	168kg S	Hydropriming	32.1
Field Pea			
Low Rainfall	168kg DS	Control livestock fallowing	3.0
Average Rainfall	168kg DS	Control livestock fallowing	0.4
High Rainfall	142kg, S	Hydropriming	0.6

Fertiliser Application Time: S = Sowing, DS = Delayed Sowing, PH = After prior crop harvest, DG= 3 months after sowing, DG1= 4 months after sowing

Hydropriming is the dominant strategy for canola, barley and wheat when disaggregated by annual precipitation. Hydropriming of seeds increases yield across all high rainfall crop production scenarios. In low rainfall years delayed application of fertiliser for field peas and wheat maximises productivity, using livestock grazing crop residue and hydropriming respectively to mitigate the impact of low rainfall on crop establishment. Canola and wheat maximise productivity with a single application of nitrogen at crop sowing utilising livestock grazing crop residue and hydropriming strategies respectively.

Winter canola yields are maximised under lower rainfall, increasing by 16.6% over the control using 168kg of fertiliser applied at sowing and livestock grazing crop residue during fallowing (Table 6). Barley has some of the highest yield variation with low and high rainfall yield maximised using 142kg and 168kg of fertiliser respectively applied at sowing. Wheat yields are improved over the control yield through calibration of fertiliser application to expected rainfall with low and high rainfall yields optimised using hydropriming combined with 168kg of fertiliser applied one month after sowing. Marginal benefits are realised for field peas with livestock grazing crop residue and 168kg of fertiliser applied one month after sowing.

Table 7: Rainfall Disaggregated Utility Optimisation

Crop	Yield Optimised Marginal Utility	Utility Variation
Canola	**$ per ha**	**%**
Low Rainfall	$156.09	49.2
Average Rainfall	-$66.80	-62.0
High Rainfall	-$34.07	-24.7
Wheat		
Low Rainfall	$58.13	5.2
Average Rainfall	$197.95	15.0
High Rainfall	$72.44	4.9
Barley		
Low Rainfall	-$4.96	-0.4
Average Rainfall	$9.96	1.4
High Rainfall	$445.31	67.2
Field Pea		
Low Rainfall	$10.52	2.3
Average Rainfall	-$3.48	-0.7
High Rainfall	-$2.10	-0.5

Economic analysis was undertaken to determine the net variation in farmer utility with alternative fertiliser management practices calibrated to forecast climatic conditions. The marginal cost of varying fertiliser inputs and application processes exceeds the marginal revenue derived from yield increases with optimising fertiliser management strategies for canola and barley when using average rainfall to determine optimal strategy (Table 7). A pareto improving economic outcome for all forecast rainfall is realised for wheat alone. Calibrating fertiliser application and fallowing management strategy to forecast precipitation increased net farmer utility for barley over the control expected returns by 67% for high rainfall but decreased utility by 0.4% with low rainfall. Canola experienced significant utility increases with low rainfall calibrating fertiliser and land management strategies to rainfall, however average and high rainfall strategies whilst improving crop productivity and yield reduced farmer utility. Field pea has little variation in farmer utility flows with increased productivity offset by increased production costs incurred.

Productivity increases and farmer utility flows are not always homogenous, with increased variable production costs offsetting crop productivity gains. When the control strategy of 120kg of fertiliser applied at sowing is compared to a split fertiliser application management method, the yield increases are offset by increased production costs, see Table 8. The split rotation strategy of 60 kg of fertiliser applied at sowing and again 3 months into the crop growth period was evaluated to determine yield and economic benefits when compared to the control under all management treatments. Minor yield increases occurred in all crops with split applications, however the increased production cost of $80.45 for labour and machinery costs associated with a second fertiliser application resulted in marginal disutility for most management methods. Field pea experienced no yield improvement with hydropriming or livestock grazing residue, the additional production costs reducing utility by the same value. Only barley had a pareto improvement in farmer utility with hydroprimed seeds and hydropriming combined with livestock grazing residue with split fertiliser application.

Table 8: Yield and Marginal Utility with 120kg fertiliser

Crop	Control (kg/ha)	Control with livestock grazing residue (kg/ha)	Hydropriming (kg/ha)	Hydropriming with livestock grazing residue (kg/ha)
Canola				
Control	1,305	1,271	1,319	1,308
Split application	1,307	1,290	1,324	1,311
Yield Variation (%)	0.1	1.5	0.4	0.3
Split Application Marginal Utility ($)	-74	29	-53	-59
Wheat				
Control	6,282	6,271	6,292	6,284
Split application	6,312	6,302	6,317	6,310
Yield Variation (%)	0.5	0.5	0.4	0.4
Split Application Marginal Utility ($)	0	3	-12	-11
Barley				
Control	6,748	6,685	6,740	6,680
Split application	6,766	6,706	6,798	6,736
Yield Variation (%)	0.3	0.3	0.8	0.8
Split Application Marginal Utility ($)	-44	-37	34	32
Field pea				
Control	2,670	2,673	2,554	2,454
Split application	2,688	2,673	2,554	2,454
Yield Variation (%)	0.7	0.0	0.0	0.0
Split Application Marginal Utility ($)	-27	-80	-80	-80

Discussion

The optimal strategy to maximise yield when forecast precipitation is not considered in field peas and wheat uses livestock and un-primed seeds with a delayed fertiliser application. Early wheat and field pea growth processes are more responsive to livestock nitrogen content on average than additional nitrogen fertiliser alone. Livestock manure contains organic matter and nitrogen benefitting wheat and field peas physiological growth patterns. Livestock grazing crop residue during fallowing is a simple cost-effective strategy to increase crop productivity, which can mitigate production risks associated with increased climatic variability when using a fixed crop fertiliser and production management strategy across seasons.

Yields for canola and barley when forecast precipitation is not considered in management *ex ante* decisions is maximised using hydroprimed seeds with traditional fallowing practices, increasing early root growth important for maximising productivity. Hydropriming is a cost-effective tool for increasing average yield. The effect is offset by increased fertiliser application costs in barley and canola when combined with fertiliser optimising practices, with the overall strategies not economically viable.

Failing to consider precipitation variation in fertiliser management decisions ignores the impact rainfall variation has on the optimal strategy. Calibrating climatic forecasts to fertiliser strategy can increase crop yields, particularly for wheat and barley. Net farmer utility is increased through calibration of wheat and barley fertiliser and management strategies to forecast rainfall.

Delaying fertiliser application until after crop establishment has occurred, combined with hydropriming increases crop yield, reducing mobilisation of fertilisers into subsoils and increasing nutrient availability for canola and wheat in high rainfall seasons. The optimal fertiliser application for wheat, barley and field peas with high seasonal rainfall is have one application of fertiliser combined with hydropriming. Calibrating fertiliser management strategies to include hydropriming is a simple cost effective technique increasing farmer utility to farmers, increasing crop nitrogen uptake and productivity.

Optimal fertiliser practices for canola utilise a split application with high seasonal rainfall. Nutrient application is spread out over the canola growth season, preventing nutrient leaching into the subsoil and maximising canola nutrient uptake, increasing productivity. Due to economic costs of split fertiliser applications farmers experience economic disutility despite increased productivity of inputs. Economic utility is maximised with a single application of fertiliser utilising higher input quantities for barley and wheat, the reduced input efficiency is offset by reduced variable labour and machinery costs associated with fertiliser application. Policy development needs to consider how to mitigate variable application costs to reduce fertiliser application quantities to encourage fertiliser input productivity through smaller, multiple applications.

The addition of livestock grazing wheat and field pea crop residue especially in high rainfall seasons adds nitrogen at no additional cost. Canola and wheat yield rainfall dependent optimising strategy benefits from livestock grazing crop residue. Farmers can utilise livestock grazing residue to reduce seasonal variation in wheat and canola, increasing soil and crop productivity.

When evaluated using disaggregated rainfall, hydropriming is the dominant strategy for high rainfall seasons, indicating the importance of providing nutrients in early establishment of crops in areas with inconsistent precipitation patterns. High rainfall years result in greater mobilisation of fertiliser nutrients through soils, negatively impacting un-primed seeds crop productivity compared to hydro primed seeds. Hydropriming is a simple low technology and low-cost technique to ensure seeds have adequate nutrition for germination and establishment, that can be used by low rainfall dryland crop producers globally to improve crop growth, yield and economic returns.

Hydropriming reduces negative yield variation in low rainfall seasons for barley, wheat and canola, within a fertiliser application strategy. With a uniform strategy of 120kg of nitrogen applied regardless of forecast precipitation, hydropriming increases crop productivity over un-hydroprimed seeds for low and high rainfall seasons. Hydropriming reduces yield variation by 3% in low rainfall seasons, with yield gains of 44 – 302kg per hectare over the control yield with the same management practices. Future policy development should consider how to motivate farmers to undertake hydropriming as a technique to reduce yield variability risks associated with precipitation variation.

Conclusion

Crop productivity increases when hydropriming is used for all crops with forecast high rainfall seasons. Hydropriming combined with conventional fertiliser treatments increases crop productivity for wheat and barley over livestock manure inputs with grazing of post harvest residue alone. Canola and barley average yield are improved regardless of the precipitation volume through hydropriming seeds. Hydropriming reduces adverse yield variation within a fertiliser management strategy with precipitation forecasting error for barley and canola across all fertiliser management strategies modelled. Hydropriming is a simple strategy to increase crop productivity and reduce management financial risks associated with precipitation forecasting error, compared to crop establishment without hydropriming of seeds.

Farmer net utility increases when utilising fertiliser and production management strategies calibrated to crop type and forecast precipitation. Hydropriming is a cost effective strategy, increasing crop productivity in low and high rainfall seasons, increasing the productivity of complementary production inputs such as livestock manure and urea fertiliser. Despite productivity increases associated with split applications of fertiliser across the crop growth season, the increased input efficiency is offset by increased marginal production application costs incurred with repeat fertiliser applications. Farmer utility and economic benefits are maximised with less productive single fertiliser applications using a larger quantity of fertiliser inputs. Future research and policy development areas can consider how to overcome the increased production application costs to improve fertiliser input efficiency and investigate whether risk management of input costs associated with climate variability can offset the increased production application costs.

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Conflict of Interest

There are no conflicts of interest for the author to declare.

References

ABARES. (2020). About My Region - Riverina, New South Wales. Retrieved from https://www.agriculture.gov.au/abares/research-topics/aboutmyregion/nsw-riverina#regional-overview

Cameron, B., Shilpakar, R., & Bigge, F. (2015). Climate Change in the North West Local Land Services Region. Retrieved from https://www.lls.nsw.gov.au/regions/north-west/land-and-water/climate-change

Imran, M., Mahmood, A., Römheld, V., & Neumann, G. (2013). Nutrient seed priming improves seedling development of maize exposed to low root zone temperatures during early growth. *European Journal of Agronomy, 49*, 7-148. doi:https://doi.org/10.1016/j.eja.2013.04.001

ABARES (2019) "Agsurf Data." In.

--- (2020) "Broadacre crop production." In., Department of Water, Agriculture and the Environment.

Alexandratos, N., and J. Bruinsma. "World agriculture towards 2030/2050: the 2012 revision." Agricultural Development Economics Division.

Ali, N., M. Farooq, M.A. Hassan, M.S. Arshad, M.K. Saleem, and M. Faran. 2018. "Micronutrient seed priming improves stand establishment, grain yield and biofortification of bread wheat." *Crop and Pasture Science* 69:479-487.

APSIM (2019) "APSIM Model Information." In CSIRO ed.

Asseng, S., P.C. McIntosh, G. Wang, and N. Khimashia. 2012. "Optimal N fertiliser management based on a seasonal forecast." *European Journal of Agronomy* 38:66-73.

Bank, W. (2020) "Commodity Markets." In T.W. Bank ed. *Commodity Markets.*

BOM (2020) "Climate data online." In *Australian Bureau of Meteorology.*

Brown, J.N., Z. Hochman, D. Holzworth, and H. Horan. 2018. "Seasonal climate forecasts provide more definitive and accurate crop yield predictions." *Agricultural and Forest Meteorology* 260:247-254.

Di Girolamo, G., and L. Barbanti. 2012. "Treatment conditions and biochemical processes influencing seed priming effectiveness." *Italian journal of agronomy* 7:25-e25.

Dickson, H. (2020) "Stubble Management Guidelines." In.

DPI (2013) "All Southern East Winter Crop Dryland Budgets 2012." In., New South Wales Government, Department of Primary Industries.

Farooq, M., S.M.A. Basra, I. Afzal, and A. Khaliq. 2006. "Optimization of hydropriming techniques for rice seed invigoration." *Seed science and technology* 34:507-512.

Farooq, M., M. Hussain, M.M. Habib, M.S. Khan, I. Ahmad, S. Farooq, and K.H.M. Siddique. 2020. "Influence of seed priming techniques on grain yield and economic returns of bread wheat planted at different spacings." *Crop and Pasture Science* 71:725.

Farooq, M., M. Usman, F. Nadeem, H.u. Rehman, A. Wahid, S.M.A. Basra, and K.H.M. Siddique. 2019. "Seed priming in field crops: potential benefits, adoption and challenges." *Crop and Pasture Science* 70:731-771.

Frischke, A. (2017) "A Visual Guide to Estimating Stubble value to livestock." In G.R.D. Corporation ed. *Groundcover Supplement Issue 129.* Western Australian Depratment of Primary Industries.

Hoben, J., R. Gehl, N. Millar, P. Grace, and G. Robertson. 2011. "Nonlinear nitrous oxide (N2O) response to nitrogen fertilizer in on-farm corn crops of the US Midwest." *Global Change Biology* 17:1140-1152.

Holzworth, D.P., N.I. Huth, P.G. deVoil, E.J. Zurcher, N.I. Herrmann, G. McLean, K. Chenu, E.J. van Oosterom, V. Snow, C. Murphy, A.D. Moore, H. Brown, J.P.M. Whish, S. Verrall, J. Fainges, L.W. Bell, A.S. Peake, P.L. Poulton, Z. Hochman, P.J. Thorburn, D.S. Gaydon, N.P. Dalgliesh, D. Rodriguez, H. Cox, S. Chapman, A. Doherty, E. Teixeira, J. Sharp, R. Cichota, I. Vogeler, F.Y. Li, E. Wang, G.L. Hammer, M.J. Robertson, J.P. Dimes, A.M. Whitbread, J. Hunt, H. van Rees, T. McClelland, P.S. Carberry, J.N.G. Hargreaves, N. MacLeod, C. McDonald, J. Harsdorf, S. Wedgwood, and B.A. Keating. 2014. "APSIM – Evolution towards a new generation of agricultural systems simulation." *Environmental Modelling & Software* 62:327-350.

Hunt, J. "Managing nitrogen for high crop yields and sustainable farming systems."

Jisha, K.C., K.C. Jisha, K. Vijayakumari, K. Vijayakumari, J.T. Puthur, and J.T. Puthur. 2013. "Seed priming for abiotic stress tolerance: an overview." *Acta Physiologiae Plantarum* 35:1381-1396.

Kaur, S., A.K. Gupta, and N. Kaur. 2002. "Effect of osmo- and hydropriming of chickpea seeds on seedling growth and carbohydrate metabolism under water deficit stress." *Plant growth regulation* 37:17-22.

Keating, B.A., P.S. Carberry, G.L. Hammer, M.E. Probert, M.J. Robertson, D. Holzworth, N.I. Huth, J.N.G. Hargreaves, H. Meinke, Z. Hochman, G. McLean, K. Verburg, V. Snow, J.P. Dimes, M. Silburn, E. Wang, S. Brown, K.L. Bristow, S. Asseng, S. Chapman, R.L. McCown, D.M. Freebairn, and C.J. Smith. 2003. "An overview of APSIM, a model designed for farming systems simulation." *European Journal of Agronomy* 18:267-288.

Khazaei, F., S. Hamzi, and H. Heidari-Sharifabad. 2009. "Improvement of seed germination traits in canola (Brassica napus L.) as affected by saline and drought stresses." *Plant Ecophysiol.* 3.

Lafrance, J., R. Pope, and J. Tack. 2011. "Risk Response in Agriculture." *NBER Working Paper Series*:16716.

LaFrance, J.T., and R.D. Pope. 2010. "Duality theory for variable costs in joint production." *American Journal of Agricultural Economics* 92:755-762.

Lassaletta, L. 2014. "50 year trends in nitrogen use efficiency of world cropping systems: the relationship between yield and nitrogen input to cropland." *Environmental Resource Letters* 9.

Mahawar, M.K., D.V.K. Samuel, J.P. Sinha, and K. Jalgaonkar. 2016. "Optimization of pea (Pisum sativum) seeds hydropriming by application of response surface methodology." *Acta Physiologiae Plantarum* 38:1-13.

McCown, R.L., G.L. Hammer, J.N.G. Hargreaves, D.P. Holzworth, and D.M. Freebairn. 1996. "APSIM: a novel software system for model development, model testing and simulation in agricultural systems research." *Agricultural Systems* 50:255-271.

Midwood, J., and P. Birbeck (2011) "Managing Stubbble." In GRDC ed., GRDC.

Patra, S., B. Mehera, S. Rout, S. Tomar, M. Singh, and R. Kumar. 2016. "Effect of hydropriming and different sowing dates on growth and yield attributes of Wheat (Triticum aestivum L.)." *Journal of Applied and Natural Science* 8:971-980.

Pope, R.D., and J.-P. Chavas. 1994. "Cost Functions under Production Uncertainty." *American Journal of Agricultural Economics* 76:196-204.

Probert, M.E., J.P. Dimes, B.A. Keating, R.C. Dalal, and W.M. Strong. 1998. "APSIM's water and nitrogen modules and simulation of the dynamics of water and nitrogen in fallow systems." *Agricultural Systems* 56:1-28.

R.B.A (2020) "Historical Data." In., Reserve Bank of Australia.

Rakkar, M.K., and H. Blanco-Canqui. 2018. "Grazing of crop residues: Impacts on soils and crop production." *Agriculture, Ecosystems & Environment* 258:71-90.

Robertson, M., and J. Lilley. 2016. "Simulation of growth, development and yield of canola (Brassica napus) in APSIM." *Crop & Pasture Science* 67:332-344.

Scanlan, C.A., N.I. Huth, and R.W. Bell. 2015. "Simulating wheat growth response to potassium availability under field conditions with sandy soils. I. Model development." *Field Crops Research* 178:109-124.

Stoorvogel, J.J., J.M. Antle, C.C. Crissman, and W. Bowen. 2004. "The tradeoff analysis model: integrated bio-physical and economic modeling of agricultural production systems." *Agricultural Systems* 80:43-66.

Thorburn, P.J., M.E. Probert, and F.A. Robertson. 2001. "Modelling decomposition of sugar cane surface residues with APSIM–Residue." *Field Crops Research* 70:223-232.

Tilman, D., K.G. Cassman, P.A. Matson, R. Naylor, and S. Polasky. 2002. "Agricultural sustainability and intensive production practices." *Nature* 418:671-677.

Van Drecht, G., A.F. Bouwman, J.M. Knoop, A.H.W. Beusen, and C.R. Meinardi. 2003. "Global modeling of the fate of nitrogen from point and nonpoint sources in soils, groundwater, and surface water." *Global Biogeochemical Cycles* 17:n/a-n/a.

van Rees, H., T. McClelland, Z. Hochman, P. Carberry, J. Hunt, N. Huth, and D. Holzworth. 2014. "Leading farmers in South East Australia have closed the exploitable wheat yield gap: Prospects for further improvement." *Field Crops Research* 164:1-11.

Warrender, C.M., G.W. Warrender, B. Smith, C. McKenzie, and R.G. Gilbert. 2010. "Accelerated testing of nutrient release rates from fertiliser granules." *Australian Journal of Soil Research* 48:668+.

Western, A.W., K.B. Dassanayake, K.C. Perera, R.M. Argent, O. Alves, G. Young, and D. Ryu. 2018. "An evaluation of a methodology for seasonal soil water forecasting for Australian dry land cropping systems." *Agricultural and Forest Meteorology* 253:161-175.

Wright, B.D. 2012. "International Grain Reserves And Other Instruments to Address Volatility in Grain Markets." *World Bank Research Observer* 27:222-260.

Zheng, B., K. Chenu, A. Doherty, and S. Chapman. "The APSIM-Wheat Module (7.5 R3008)."

Zou, H., Y. Ling, X. Dang, N. Yu, Y. Zhang, Y. Zhang, and J. Dong. 2015. "Solubility characteristics and slow-release mechanism of nitrogen from organic-inorganic compound coated urea.(Research Article)(Report)." 2015.