System's perspectives on the relationship between soil water dynamics and the efficacy of stubble and fertiliser management

Verburg K[1], McBeath TM[2], Armstrong RD[3], Sandral GA[4] and Kirkegaard JK[1]

[1] CSIRO Agriculture and Food, GPO Box 1700, Canberra, ACT 2601, Email: kirsten.verburg@csiro.au
[2] CSIRO Agriculture and Food, Waite Campus, Locked Bag 2, Glen Osmond, SA 5064.
[3] Agriculture Victoria Research, PMB 260, Horsham, VIC 3400.
[4] NSW Department of Primary Industries, Wagga Wagga, NSW (now GRDC)

Abstract

Stubble and fertiliser management practices aim to improve water and nutrient availability to crops by influencing the soil water dynamics or responding to it. However, their intended effects, such as improved yield, are not always realised. We use three simulation case studies to analyse soil water dynamics in a system's context. The results indicate that the efficacy of stubble and fertiliser management practices and knowing when to use them relies on understanding soil water dynamics.

Keywords

APSIM, simulation, rainfall pattens, soil phosphorus, nitrogen, enhanced-efficiency fertilisers

Introduction

Soil water is the major determinant of potential yield in dryland agriculture. Understanding how much plant available water (PAW) the crop has access to influences management decisions such as if and what to sow or how much fertiliser to apply. Stubble management is often used with the aim to influence the soil water dynamics and increase PAW (Scott et al. 2013) while other management practices are designed to improve water and fertiliser use efficiency by responding to certain soil water dynamics. In drier climates, deep placement of P (Singh et al. 2005) and deep sowing (Flohr et al. 2021) have been proposed to avoid the dry surface soil and make better use of resources in subsurface soil layers with higher soil water contents. Conversely, in wetter environments, controlled-release fertilisers (CRF) have been proposed for systems where excess water results in N losses via deep drainage or denitrification under waterlogging conditions.

The influence of these management practices on improving water or nutrient availability has been demonstrated in controlled experiments. However, their intended benefits, e.g. improved crop yield, are not always realised at the systems level in variable climates. Cropping systems modelling can provide insights into interactions between climate, soil, crop and management practices (Keating et al. 2003). Here we analyse interactions of agronomic management with soil water dynamics and consider how this might improve the development of management guidance.

Case studies: context and methodology

Simulation studies were derived from several projects (Table 1) and were performed with the APSIM Classic model (Keating et al. 2003). Simulations were run using historical point-patch climate data from SILO (Jeffrey et al. 2001). The context and details for each case study are as follows.

Stubble management

Surface residue cover increases infiltration and reduces the rate of soil evaporation. Yet, several summer-fallow stubble management experiments have reported limited or no effect on soil water at sowing and subsequent crop performance (e.g., Sadras et al. 2012; Verburg et al. 2012; Hunt et al. 2013; Kirkegaard et al. 2014). The small or negligible differences in soil water accumulation over summer were also predicted using simulation (Verburg et al. 2012). However, the simulations and data from weighing lysimeters also showed that residue cover did reduce evaporative losses in autumn and winter when there is more frequent rainfall and lower evaporative demand. This raises the question as to whether stubble management can alter surface soil water dynamics in the period just after sowing to benefit germination, emergence and early vigour, especially in earlier-sown crops. The fallow management simulations of Verburg et al. (2012) were re-analysed to quantify effects of stubble management on surface soil water status.

As soil water effects on rate of germination and emergence are described as function of soil matric potential (e.g., Dracup et al. 1993), we express soil water status as a soil water index used in APSIM for a variety of water stress factors (e.g., crop models, soil N model, soil P model):

$$soil\ water\ index = \frac{(soil\ water\ content - crop\ lower\ limit)}{(drained\ upper\ limit - crop\ lower\ limit)} \qquad \text{(Eq. 1)}$$

Deep or dual soil P placement

Moist subsurface soil has been the target of deep or dual soil P placement (Singh et al. 2005) to avoid soil 'stranding' fertiliser P in the drier surface. Deep soil P has shown benefits in northern Australia (M.J. Bell, pers. comm.) but the benefits in southern Australia are unclear. We simulated the surface and subsurface soil water dynamics for wheat grown on a Vertosol in summer and winter dominant rainfall to understand the potential to avoid fertiliser placement in dry soil.

Use of CRF

Controlled-release fertilisers aim to synchronise timing of N release with uptake by the crop to keep soil mineral N low and reduce N loss. Reduced N loss, increased fertiliser N use efficiency and increased yield have been demonstrated, but efficacy has been variable (Verburg et al. 2014). A set of wheat simulations across WA, SA, Vic and NSW were adapted to provide a first screening of likely benefits within the grains industry by simulating N response curves (0, 60, 120 and 240 kg N/ha) for urea and a CRF in presence of background soil N of 61-75 kg N/ha (50 kg N/ha in 0-60 cm).

Table 1. Simulation case studies

Aspect explored	Reference / Project	APSIM version and climate
Effect stubble management (bare, flat, standing) on surface soil water dynamics	Verburg et al. (2012)	v.5.2; wheat, SWIM; Wagga Wagga NSW station 73127
Surface soil water dynamics in summer and winter dominant rainfall climates in the context of deep or dual P placement	Verburg et al. unpublished, GRDC Maximising uptake of P by crops (southern)	v.7.10; wheat, SoilWat; APSoil 746; Longerenong Vic (var. Yitpi, station 79028), Dalby Qld (var. Lincoln, station 41023)
Yield and N loss benefits of controlled release fertilisers	Verburg et al. unpublished CSIRO Better Nutrient Delivery project	v.7.4; wheat, SoilWat; Hunt and Kirkegaard (2011) + APSoil 588, Port Lincoln SA station 18017

Results and Discussion

Stubble management differ depending on timing and soil depth considered

Stubble management affected simulated surface soil water status, with stubble retention increasing the frequency of higher soil water index values at the end of March and increasing the median value in April (Figure 1). Stubble configuration had less effect on the interquartile range, but stubble flattened at harvest did increase the median soil water index. Translation into a beneficial effect on emergence requires quantification of critical thresholds and would also need to consider temperature and stubble load. Standing stubble decomposes slower and may create a higher stubble load post-sowing if flattened then. The results will likely be soil and climate dependent, as these influence the surface soil wetting on account of rainfall frequency and evaporative demand (Verburg et al. 2012).

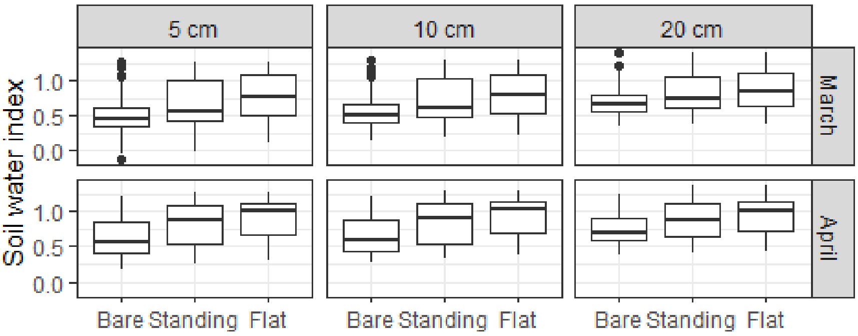

Figure 1. Effect of stubble treatments on simulated soil water index (Eq. 1; 1960-2006, Wagga Wagga, NSW) at different depths at the end of March and April; bar is median, box is interquartile range.

Surface soil water dynamics needs to be considered for effectiveness of deep or dual P placement
Rainfall distribution has a marked effect on simulated surface and subsurface soil water dynamics (Figure 2). The summer dominant rainfall at Dalby, Qld caused considerable soil drying during the wheat growing season, with the subsurface soil (20-30 cm) water index wetter than the surface soil in 90 % of years until late June and around 50-60 % of years thereafter. In contrast, at Longerenong Vic, autumn rains wet up the soil, with a slight lag in the subsurface soil, and winter rain usually kept the soil wet until spring. Consequently, the subsurface soil water index tended to be lower than that of the surface soil in early vegetative stages in 65 % of years (on average between sowing and booting), although there was considerable seasonal variability.

The simulation results confirm the case for deep or dual soil P placement in climates like that of Dalby, but indicate that benefits will not be present every season, especially for P uptake after late June. Benefits are less likely in climates like that of Longerenong, although this will likely be sensitive to texture of the surface soil, which affects the time to wetting of the subsoil in autumn and the extent of surface drying in early spring. Further analysis of climate × soil texture effects will be required to characterise the benefits in regions with uniform to winter dominant rainfall. These observations on surface soil water dynamics may also be relevant to practices of deep sowing.

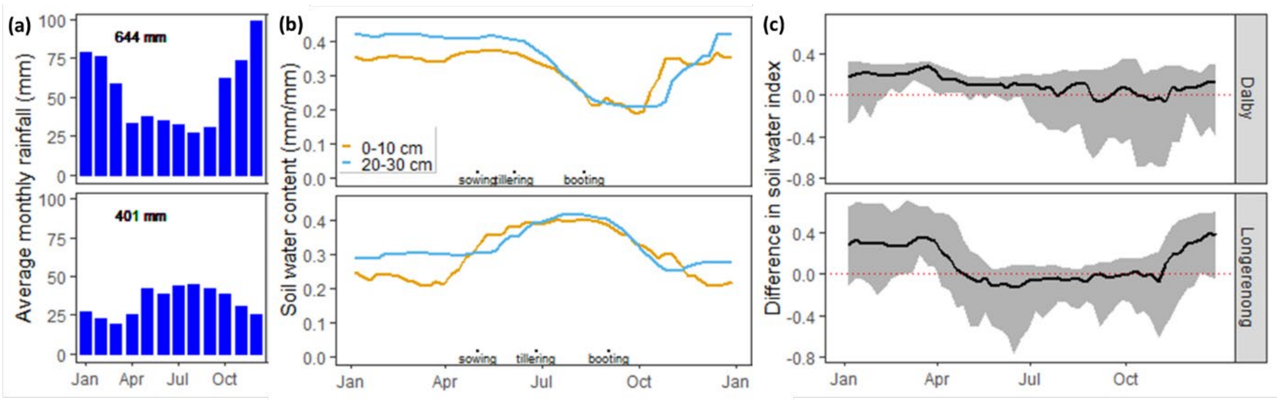

Figure 2. (a) Average monthly rainfall, (b) median weekly simulated soil water content in surface and subsurface (1985-2020), and (c) 10th, 50th and 90th percentile differences in soil water index (1985-2020) between Dalby, Qld (top) and Longerenong, Vic (bottom). Soil water index relative to crop lower limit and drained upper limit as defined in Eq. 1, where a positive difference means subsurface soil is wetter.

Controlled release fertiliser efficiency depends on soil water dynamics and yield potential
At all 37 sites of Hunt and Kirkegaard (2011) the mean predicted in-season N loss from leaching and denitrification was less than 20 kg N/ha at the highest urea N rate of 240 kg N/ha. Reduction in N loss from CRF use was hence small too, although seasonal variability was large (Figure 3). Sites with greatest N loss were those with high rainfall, and winter dominant rainfall in combination with heavy soil (denitrification loss) or highly permeable soil (deep sands, leaching).

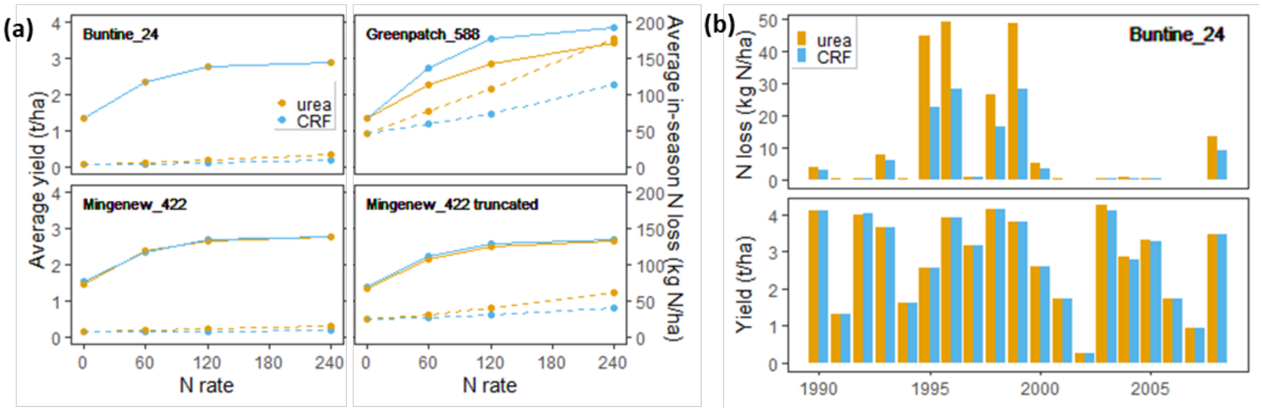

Figure 3. Comparison of urea and controlled release fertiliser (CRF); (a) average yield (solid) and in-season N loss (dashed) at 4 sites in response to N rate, (b) annual yield and N loss for Buntine site.

Limited potential for N loss appears to limit benefits of CRF across much of the grain belt, although larger N loss and N loss reductions have been predicted for some sites where growers have trialled CRF (e.g., Greenpatch in Figure 2), indicating that the set of 37 sites does not represent the full range of scenarios. Soil parameterisations have not yet been verified for prediction of N loss and ammonia volatilisation was not considered due to an assumption of direct drill application. Deep sands in the simulation set often had a depth of 2.5 m. Reducing this to 1.5 m increased N loss and CRF benefit (e.g., Mingenew_422_truncated) indicating that leaching of N within the profile is higher. Greenpatch was a very shallow permeable soil (PAWC 41 mm), where CRF could reduce N loss considerably. Yield benefits remain small though due to yield being constrained by the amount of water that the soil can hold. Agronomic benefits from CRF are therefore determined by both soil water dynamics (driving N loss potential) and yield potential, something which was also noted in simulations of sugarcane systems where waterlogged conditions in principle conducive to CRF benefit reduced yield potential and limited CRF benefit (Verburg et al. 2018).

Conclusion

These case studies reinforce that system's context and climatic conditions affecting soil water dynamics need to be considered when extrapolating management guidelines to other regions. While stubble management had been shown to have limited impact on PAW at sowing, it has potential to impact positively on surface soil water available for emergence and early vigour. The benefits of deep or dual soil P placement and CRF will be determined by specific patterns in soil water dynamics, in the absence of which these practices may not achieve the anticipated potential.

Acknowledgements

The research presented here was funded by CSIRO and GRDC (CSO232, CSP00111, DAN2001-033RTX). We acknowledge the helpful discussions within the wider project teams from CSIRO, NSW DPI, Agriculture Victoria, SARDI, Agronomy Solutions and University of Adelaide.

References

Dracup M, et al. (1993) Temperature and water requirements for germination and emergence of lupin. Australian Journal of Experimental Agriculture 33, 759–766.

Flohr BM, et al. (2021) Redefining the link between rainfall and crop establishment in dryland cropping systems. Agricultural Systems 190, 103–105.

Hunt JR, Kirkegaard JA (2011) Re-evaluating the contribution of summer fallow rain to wheat yield in southern Australia. Crop & Pasture Science 62, 915–929.

Hunt JR, et al. (2013) Summer fallow weed control and residue management impacts on winter crop yield through soil water and N accumulation in a winter-dominant, low rainfall region of southern Australia. Crop & Pasture Science 64, 922–934.

Keating BA, et al. (2003) An overview of APSIM, a model designed for farming systems simulation. European Journal of Agronomy 18, 267–288.

Kirkegaard JA, et al. (2014) Improving water productivity in the Australian Grains industry – a nationally coordinated approach. Crop & Pasture Science 65, 583–601.

Sadras VO, et al. (2012) Contribution of summer rainfall and nitrogen to the yield and water use efficiency of wheat in Mediterranean-type environments of South Australia. European Journal of Agronomy 36, 41–54.

Scott BJ, et al. (2013) Developments in stubble retention in cropping systems in southern Australia. Report to the GRDC. (https://grdc.com.au/resources-and-publications/all-publications/publications/2013/12/developments-in-stubble-retention)

Singh DK, et al. (2005) Increasing phosphorus supply in subsurface soil in Northern Australia: Rationale for deep placement and the effects with various crops. Plant and Soil, 269, 35–44.

Verburg K, et al. (2012) Fallow management in dryland agriculture: Explaining soil water accumulation using a pulse paradigm. Field Crops Research 130, 68–79.

Verburg K, et al. (2014) Use of enhanced efficiency fertilisers to increase fertiliser nitrogen use efficiency in sugarcane. In 'A review of nitrogen use efficiency in sugarcane. SRA Research Report'. (Ed MJ Bell) pp. 229–295, Sugar Research Australia, Brisbane, Qld.

Verburg K, et al. (2018) Why benefits from controlled release fertilisers can be lower than expected on some soils. International Sugar Journal 120 (1440), 936–945.