Cropping Intensification in a Semiarid Environment of Australia

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Abstract

In the semiarid Mallee region of southern Australia, risk management is largely based on a conservative, low input approach with substantial opportunity costs (missing the benefits of wet seasons) and low yield per unit available water. We combined field and modelling experiments to evaluate an intensive, flexible cropping approach based on (i) an opportunistic combination of crops, including wheat, canola, and grain legumes, and (ii) a close matching of nitrogen input to soil and seasonal conditions. In a four-year field trial established on a coarse textured soil, an intensive cropping approach doubled gross margin and halved its coefficient of variation in relation to current practice. Modelling experiments (a) confirmed the long-term economic benefits of the intensive cropping approach tested in the field, (b) highlighted its neutral or slightly beneficial impact on nitrogen leaching and deep drainage, and (c) unveiled a key trade-off whereby water-use efficiency can be increased at the expense of nitrogen-use efficiency; this is consistent with the theoretical expectation that plant growth is maximized when all resources are equally limiting. The approach to intensification in this research provides a platform to improve production and profit, and to reduce its seasonal variation with neutral or slightly positive effects on environmentally relevant processes.

Media summary

Where growers receive little or no subsidies, cropping intensification and improved efficiencies are the principal means to ensure farm economic viability. Here we show how cropping intensification can improve production, profit, and water-use efficiency in a dry environment.

Key Words:

Water-use efficiency, nitrogen leaching, trade-off, dryland agriculture, fertiliser

Introduction

There is a double effect of low, unreliable rainfall on crop production (Fig. 1). The picture of a crop under drought represents the most obvious of these effects – dry soil, small wilted plants, little or no grain to harvest. The second effect is more subtle, and involves a common human attitude to risk: facing potentially large economic losses, farmers in many dry regions often try to cut costs (e.g. minimising use of fertiliser), thus reducing their loss in poor seasons. An unwanted consequence of this low input approach is that shortage of nutrients can constrain yield in wetter seasons. A reinforcing loop is thus established whereby shortage of water restricts crop growth and yield, and brings forth a low-input, conservative farming approach which contributes to further reduction in production (Fig. 1). The processes outlined in Fig. 1 are common in the semiarid Mallee region of Australia. This approach to farming, combined with low soil fertility, leads to large unproductive water losses (horizontal gap between points and line in Fig. 2) and low actual yields in relation to attainable yield (vertical gap in Fig. 2).

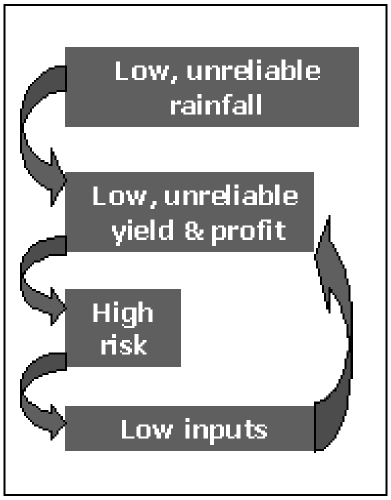


Fig. 1 The double effect of low rainfall on crop yield

Our working hypothesis is that cropping intensification and fertiliser inputs matching soil and seasonal conditions could contribute to break the loop of low input ↔ low yield dominant in the Mallee, and therefore improve farm profit and water-use efficiency.

Field assessment of intensive cropping

A field trial compared current low-input practice with a flexible, intensive cropping approach. The approach is flexible because it is based on the opportunistic selection of crops, rather than on fixed rotations. Wheat, canola, grain legumes or other cereal crops and pastures are the cropping options. The criterion to grow canola or legume break crops is an early rainfall break, which increases the likelihood of achieving profitable yields. Otherwise, wheat is the preferred option provided there are no major disease or weed problems. A high incidence of grass weeds or inoculum of wheat root diseases, switches the decision towards the least preferred option eg. rye or pasture. The approach is intensive, in comparison with low-input current practice, because crops are grown every year, and it aims at closely matching N fertiliser to soil and seasonal conditions which determine crop nutritional requirements. Rates of N fertiliser are calculated taking into account (a) measured soil water content and inorganic N at sowing, (b) estimated rainfall and N mineralisation during the growing season. Further details can be found in Sadras & Roget (2004).

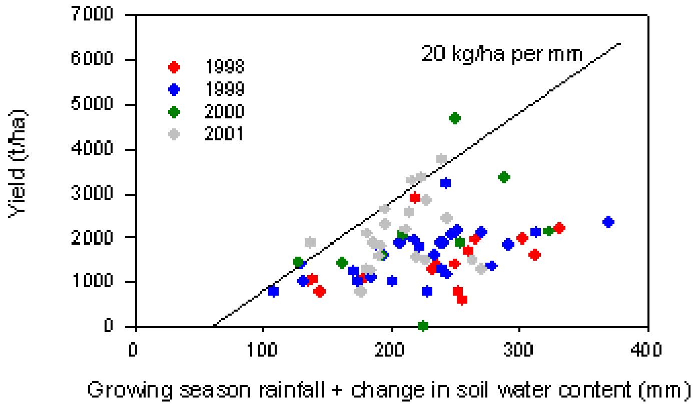


Fig. 2. Actual grain yield of wheat crops in the Mallee (circles) is generally below the attainable yield (solid line) due to an array of factors, including shortage of nitrogen in a system characterised by soils with low levels of organic matter, and low use of fertiliser.

After four seasons, the profit of the intensive approach was doubled and its coefficient of variation was halved in relation to current district practice (Table 1). The main benefits of the intensive approach included the possibility of growing successive wheat crops provided there were no major biological constraints (1998-1999); the opportunistic use of canola as a break crop after an early break (2000) and the high wheat yield following canola (2001). The fixed wheat-pulse approach illustrated the high risk of untimely sown grain legumes (1999) and the benefits of growing wheat after a legume crop (2000).

Table 1. Gross margin (AU$ ha^{-1} $year^{-1}$) of an intensive, flexible cropping strategy compared to fixed rotations with low (wheat/pasture) or high inputs (wheat/pulse) on a sandy-loam soil at Waikerie (34? S, 140? E). Annual rainfall averages 267 mm, of which 66% concentrates in the growing season (April to October). Gross margins were based on 5-year average of commodity prices and actual costs.

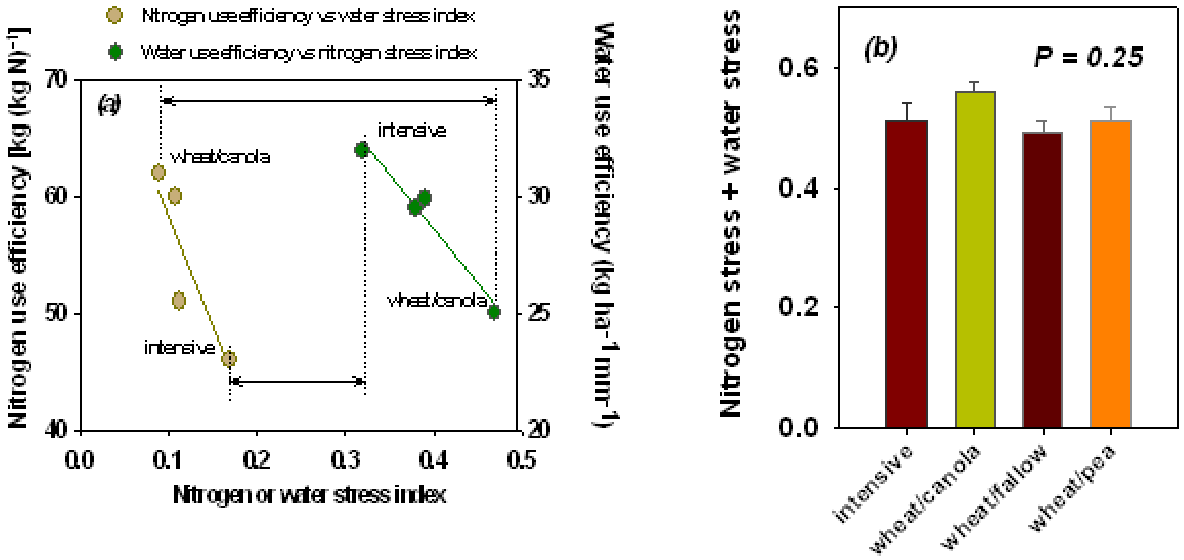
Year	Cropping strategy		
	Intensive	Wheat/Pasture	Wheat/pulse
1998	232 (wheat, 2.5[1])	221 (wheat, 2.2)	232 (wheat, 2.5)
1999	110 (wheat, 1.6)	40 (pasture)	-87 (vetch, 0)
2000	234 (canola, 1.2)	143 (wheat, 1.5)	222 (wheat, 2.3)
2001	306 (wheat, 3.1)	40 (pasture)	162 (field pea, 1.3)
Avg.	221	111	132

[1] grain yield (t ha^{-1} $year^{-1}$)

Modelling the fate of water in the system, and its interactions with nitrogen

The flexible, intensive farming approach and three low input, fixed-rotations were modelled using CropSyst (St?ckle et al 2003) and long-term weather records (43 years) for Waikerie. Fixed rotations included wheat/canola, wheat/field peas, and wheat/fallow. The following discussion concentrates on the comparison of the approaches with extreme responses, i.e. intensive and fixed wheat/canola. Long-term simulations involving seasonal rainfall variation from 53 to 334 mm, confirmed the production and profit benefits of intensive cropping found in the field. Median rate of nitrogen leaching estimated with a cascade method for soil water distribution, was 0.01 kg N ha^{-1} yr^{-1} for the intensive cropping strategy compared with 2.6 kg N ha^{-1} yr^{-1} for low input, fixed wheat/fallow rotation, 0.09 kg N ha^{-1} yr^{-1} for wheat/canola and 0.03 kg N ha^{-1} yr^{-1} for wheat/legume. Despite substantial increase in the dose of fertiliser required to reduce the gap between actual and attainable yield, modelled rates of N leaching did not increase with respect to current practice due to the close matching of fertiliser inputs and soil and seasonal conditions.

Cropping approach did not affect evapotranspiration (ET) of wheat crops but had a significant effect on the fraction of ET accounted for by crop transpiration, which increased from an average 0.39 in low input wheat/canola to 0.55 in the intensive cropping approach. Wheat crops in the intensive approach had a much lower nitrogen stress, at the expense of a larger water stress, than their counterparts in the wheat/canola, low input approach. Associated with this trade-off, the efficiency in the use of water by wheat in the intensive cropping approach was 28% greater than for their counterparts in the wheat/canola approach, and its efficiency in the use of nitrogen was 26% lower (Fig. 3a). The different cropping approaches did not change the overall stress of wheat crops (Fig. 3b). Narrowing the gap between nitrogen and water stress, as illustrated by the arrows in Fig. 3a, increased crop biomass and grain yield: the absolute value of the difference between nitrogen and water stress indices accounted for 52% of the variation in shoot biomass (Fig. 3c) and for 73% of the variation in grain yield (both $P < 0.0001$). This is consistent with the notion that growth of stressed plants is maximised when all resources are equally limiting (Bloom et al 1985).



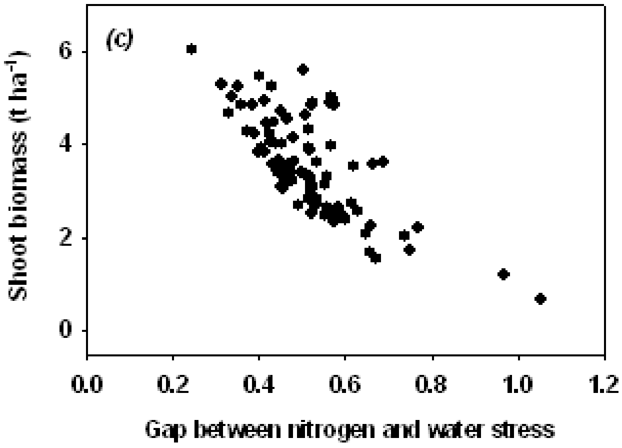


Fig. 3 (a) Simulated nitrogen use efficiency of wheat crops increases with decreasing water stress, and water use efficiency increases with decreasing nitrogen stress. Stress indices range from 0 (no stress) to 1 (maximum stress). Efficiencies were calculated as ratios between shoot biomass and nitrogen uptake or evapotranspiration. The arrows show the gap between nitrogen and water stress intensity in the extreme treatments. (b) Overall stress (nitrogen stress index + water stress index) of wheat crops was independent of cropping approach. (c) Crop productivity increases when the gap between nitrogen and water stress decreases.

Acknowledgements

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