Estimating grain yield with the French and Schultz approaches Vs simulating attainable yield with APSIM on the Eyre Peninsula

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Abstract

Simple relationships between rainfall and yield ignore the fact that interactions between soil type, plant available soil water and crop growth are strongly influenced by the amount and distribution of rainfall as well as extreme events such as frost or high temperatures. In low rainfall wheat growing regions such as the Eyre Peninsula where spatial variability in crop performance is related to soil variation and sub-soil constraints, the French and Schultz calculation of attainable yield has limited application to setting realistic yield targets. In order to accurately model the system and be relevant to developing lower risk and responsive farming systems, there is a minimum amount of system complexity that a model must be able to represent. In experimental trials in various seasons, sites and soil types, APSIM accurately predicted grain yield and was able to model the differential effect that dry finishes have on shallow heavier textured soils compared with less constrained lighter textured soils. These simulations were most accurate where the sites were properly characterised for water holding capacity, rooting depth and chemical or physical constraints, and information was known about crop variety, planting time, fertiliser application, management and daily climate.

Key Words

Water use efficiency, crop simulation, attainable yield, soil type, Eyre Peninsula, APSIM.

Introduction

The aim of this work was to collate historically measured wheat yield data from the Minnipa Agricultural Centre (MAC) and from recent on and off-station experimental work and compare them with predictions of the French and Schultz potential yield calculation and the predictions made by the systems simulation model APSIM (Keating et al. 2003). Understanding the complex interactions between soil type, rainfall distribution and management are essential for developing more profitable and less risky farming systems for Eyre Peninsula (EP) and models are used to help achieve this aim.

The French and Schultz (F&S) potential yield calculation is a simple and widely used method for predicting potential grain yield. It is based on a collection of data (French and Schultz, 1984a, 1984b) to define a linear boundary function describing attainable yield per unit of water use (i.e. 20 kg grain/ha.mm for wheat grain). A loss term, or the x-intercept of this line, accounting for soil evaporation was 110 mm, although in reality this ranges from 30-170 mm, depending on soil type and rainfall pattern. The main criticisms of the F&S approach in the literature have included not accounting for the timing of in-season rain, not considering runoff or drainage or out of growing season rainfall on the water budget and assuming constant seasonal evaporation (Angus and van Heerwaarden 2001). Despite these criticisms, the F&S approach remains popular with farmers and consultants and adaptations to the method have been attempted to extend its applicability from the 275 to 450 mm average annual rainfall zone where it was derived (Hancock 2007) or to other crop types such as Canola (Robertson and Kirkegaard 2005). Sadras and Rodriguez (2007) also re-interpreted the x-intercept by analysing the size and structure of rainfall events.

A more complex approach to predicting crop performance is the use of APSIM, a systems model that simulates the major processes that occur while growing crops and pastures. These include the nitrogen and carbon dynamics in soil, soil water balance (including drainage, leaching and runoff) and crop growth and interactions with daily temperature, radiation and rainfall. APSIM requires accurate information about soil type (water holding capacity, rooting depth, chemical or physical constraints, carbon and nitrogen content), information about crop variety, planting time, fertiliser application and daily climate.

In this paper, predictions of water limited grain yield using the original and modified F&S approaches, and the APSIM model were compared with historical datasets from MAC and its surrounds.

Methods

Historical wheat yield measurements from MAC and information from more recent on-and off-station experimental work were collated as follows:

1. Annual average grain yield of all paddocks at MAC that were sown to wheat for the seasons between 1972 and 2007. This includes paddocks that have been in long term cereal or other rotations as well as paddocks coming out of pasture rotation. No management information about variety, planting date, fertiliser or stage of rotation was available.

2. Measured grain yields for wheat grown in the MAC paddock N1 during the seasons of 1977, 1986, 1990, 1995, 1998, 2000, 2002, 2006, 2007. Information such as planting date, cultivar and fertiliser application were available.

3. Wheat trials were conducted separately on heavy and loam soil types in 2005 and 2006 at MAC, Tuckey and Mudamuckla on the upper EP. Information about planting date, cultivar and fertiliser application were available as well as soil moisture and mineral N at sowing. The two soil types at each site were characterised for the drained upper limit (DUL), crop lower limit (CLL), rooting depth, bulk density, organic carbon and chemical constraints such as salt and boron.

For each of the sites and seasons, attainable yield was calculated using a modified French and Schultz approach described by Hancock (2007). This approach adjusts the April to October rainfall to include some summer rainfall, and in the event of April to October rainfall being less than 200 mm reduces the loss term down. APSIM was used to simulate daily wheat growth by parameterising as follows:

MAC annual average

APSIM was used to simulate the growth of wheat and its interaction with soil water, nitrogen and climate for heavy and a loam soils that were characterised at MAC. The heavy soil had a rooting depth restricted to 40 cm, plant available water capacity (PAWC) of 38 mm. The loam had a rooting depth of ~60 cm and plant available water capacity of 108 mm. Daily weather records recorded at MAC were obtained from SILO (Jeffery *et al.* 2001). Other assumptions about the management of the wheat crops include: The wheat cultivar Yitpi was sown at 150 plants/m2 in a sowing window that opened 15 May and closed 30 June. Sowing took place during this window if 10 mm of rainfall was received over 3 days and 20 mm of plant available water was in the soil profile. Based on the measurement of mineral N made in 2006, the soil profile was assumed to contain 167 kg/ha of mineral N in the loam and 228 kg/ha in the heavy soil and this amount was reset yearly. While some of this N is below the rooting zone, it is common to measure large amounts of mineral N pre-sowing in these soil types, particularly after medic pasture. An addition of 10 kg N/ha was applied at sowing in line with the average MAC farm practice.

MAC paddock N1

The grain yield was simulated as for data set 1, but with actual planting dates, fertiliser application and cultivar. In order to calculate a predicted wheat yield for both of MAC datasets, we assumed that one-third of the cropping country was on the heavy soil type and two thirds was loam. This assumption was based on the interpretation of an EM map for paddock N1.

Results

Simulating the datasets 1&2 with limited soils and management information

Using the MAC annual average dataset for the seasons between 1972 and 2007, yield predictions made using the modified F&S approach or simulating the individual seasons with APSIM were plotted against April to October rainfall (Figure 1). The MAC measured yields reach a maximum of about 2.9 t/ha with 287 mm April to October rainfall. In the seasons where rainfall exceeded the 287mm, wheat yield plateaued at about 2 t/ha, presumably due to other constraints such as N which may leach in years of high rainfall. Predictions of grain yield based on the standard and modified F&S approaches over predict grain yield in most seasons. A regression of the predicted against observed (modified F&S) yields resulted in an r^2 = 0.62 and a RMSE of 1.65 t/ha, n = 35 (Figure 2).

Predictions of grain yield using APSIM are more closely matched to the measured data for April to October rainfall up to 300 mm, but in seasons where rainfall exceeds this amount, APSIM also over predicted yield. A regression of the predicted against observed yields result in an r^2 = 0.66 and RMSE of 0.64 t/ha, n = 35 (Fig. 2a). Using APSIM to simulate a subset of seasons for MAC paddock N1 where planting date, cultivar and fertiliser application were available to initialise the model substantially improved the regression between predicted and observed and the RMSE n=9 (Fig. 2b).

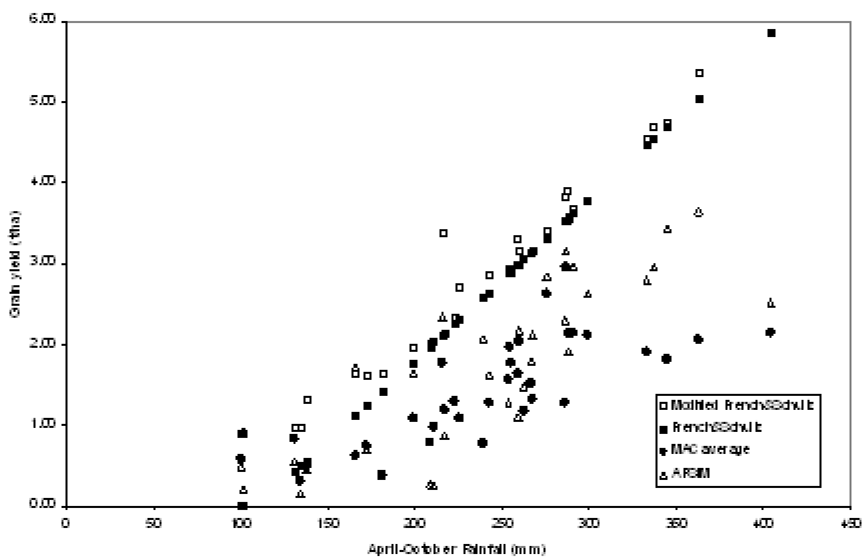

Figure 1. The yearly average MAC wheat yield, the predicted grain yields using the French and Schultz and APSIM approaches plotted against the April to October rainfall in each season 1972 to 2006.

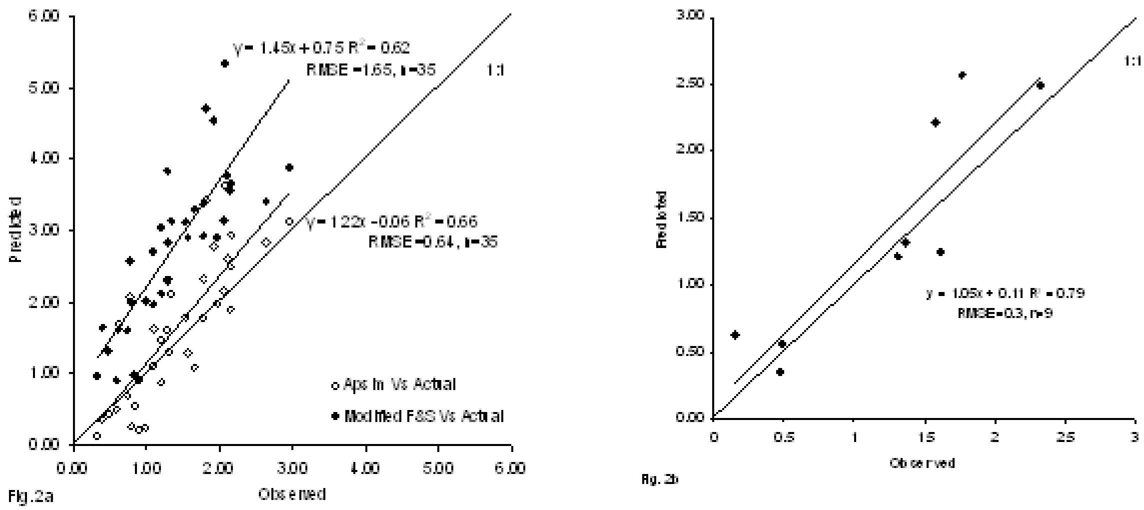

Figure 2 a. The modified French and Schultz and APSIM predicted grain yields (t/ha) plotted against observed average MAC wheat yield for seasons between 1972 and 2006 and (Figure 2b) observed grain yields for wheat grown in the MAC paddock N1 during the seasons of 1977, 1986, 1990, 1995, 1998, 2000, 2002, 2006, 2007 plotted against APSIM prediction yield using planting date, cultivar and fertiliser application for those seasons.

Simulating dataset 3 with detailed soil and management information

At each of the sites, trials were undertaken on a fully characterised heavy textured and loam textured soil (data not shown). The heavy soils are typically higher in clay content, have subsoil constraints that limit potential rooting depth and lower the plant available water capacity (PAWC) (Nuttall *et al.* 2003). On the loam soils, PAWC is typically larger because the potential depth of rooting is deeper. As a result, when the profile fills, soil water supply increases and plants can access available soil water later into the growing season. In the trials conducted during 2005, wheat grown on the loam soils out-yielded wheat grown on the heavy soils in all cases, with the exception of Tuckey in 2005 (Table 1) (Hancock 2006). It is not uncommon to see “flip-flops” for different seasons where some parts of the paddock perform the best in dry years (i.e. the lighter parts) while other parts of the paddock can perform better in the wetter years (the heavier ground with subsoil constraints). By carefully characterising the water holding characteristics of these soils and sowing conditions, APSIM was able to simulate the effect of rainfall amount and distribution on available soil water and its interactions with crop growth resulting in a good prediction of grain yield (r^2=0.88, RMSE = 0.26 t/ha, n= 16) importantly, the effects of soil type difference and season interactions could be modelled.

Table 1. Plant available water capacity (PAWC) and rooting depth of heavy and loam soils at 4 sites on upper Eyre Peninsula and observed and APSIM predicted wheat grain yield (t/ha) for 2005 and 2006.

				Wheat yield (t/ha) 2005			Wheat yield (t/ha)		
Site	Soil	PAWC (mm)	Root depth (cm)	Obs.	Pred. APSIM	Pred. F&S	Obs.	Pred. APSIM	Pred. F&S
Tuckey	Heavy	76	40	2.17	2.22	3.42	0.28	0.31	0.68

	Loam	70	70	1.88	2.42	-	0.79	0.31	-
Mudamuckla	Heavy	29	30	1.12	1.10	2.58	0.36	0.44	0.92
	Loam	114	100	1.26	1.73	-	0.85	0.45	-
Minnipa (W)	Heavy	33	40	1.21	1.37	3.14	0.29	0.43	1.1
	Loam	163	120	2.01	1.94	-	0.56	0.63	-
Minnipa (Y)	Heavy	33	40	1.52	1.59	-	0.22	0.36	-
	Loam	163	120	2.32	1.98	-	0.48	0.57	-

Nb. W and Y refer to wheat cultivars Wyalkatchem and Yitpi. Tuckey and Mudamuckla were sown to Wyalktachem in 2005 and Yitpi in 2006. Growing season rainfall at Tuckey, Mudamuckla and MAC was 267, 239 and 281 mm in 2005 and 111, 102 and 94 mm in 2006 respectively.

Conclusion

The interactions between soil type, available soil water and crop growth is largely determined by the amount and distribution of rainfall. Models that ignore these interactions have limited ability for predicting realistic ‘attainable’ grain yields in low rainfall regions where sub-soil constraints are common. Precision Agriculture requires an understanding of within paddock and season-to-season yield variation, and in low rainfall regions particularly, this is strongly related to soil variation. Therefore despite modifications to the simple empirical approaches like French and Schultz to account for more off season water storage or rainfall patterns, this paper demonstrates that soil type has an overriding factor on crop performance at a particular location. While APSIM is a seemingly complex model requiring substantial investment in soil characterisation and the collation of management and, climatic information, we believe it is the minimum amount of complexity required to represent the production system in this environment. Once this investment is made, the model can be employed to assist farmers manage risk. To make APSIM more relevant to the EP farming systems, a co-ordinated effort should be undertaken to characterise a wide range of soils, parameterise and validate crop types and varieties (e.g. growth, phenology), and better understand the dynamics of rainfall, evaporation, soil type and management. This is especially important in the challenges we face in adapting to climate change.

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