EVALUATION OF WAGGA WAGGA SHIRE WHEAT YIELDS USING SIMULATED PRODUCTION AND WATER BALANCE

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Abstract

The simulation model SIMTAG was used to evaluate wheat production in the Wagga Wagga Shire using 45 years of weather data. SIMTAG simulates attainable (?potential?) yields, that is nutrient non-limiting, and disease and weed free crops. Average simulated yield on a red-brown earth for normal sowings was 4.22 t/ha compared to the 1.66 t/ha Shire yield. Current yields are 50% of attainable and that percentage has been increasing by 5% per decade or a steady 26 kg/ha/yr. Simulations resulted in a yield loss of 5% per 1-week delay in sowing after late April, comparable with field results. A leaf area reduction factor was used in the model to simulate the impact of poor crops on water balance. Simulated yields of poor crops were comparable with Shire yields. Average outflows (deep drainage, runoff) nearly doubled for poor crops. Median annual outflows were 0 and 45 mm for good and poor crops, respectively. Seasonal variability in soil evaporation (81-301 mm) and outflows (0-341 mm) make seasonal rainfall unreliable as a measure for water use efficiency.

Key words: Wheat modelling, attainable yield, historic production, drainage, sowing date, intensive agriculture

Objective tools are needed to evaluate possible improvements in both agricultural production and catchment health to attain or maintain profitable and sustainable farming systems. The health of many catchments in the wheat-sheep zone would improve considerably if production of crops and pastures were optimised through sound management of crop (type, variety) - pasture (type, composition) rotation (sequence durations), reduced tillage and stubble retention. These factors have major implications on fertility, structure, biological activity, acidity and organic matter of the soil, on weed, disease and pest control, and affect water balance and salinity in the catchment. Optimum returns, best use of water and minimised degradation depend on change of land use at appropriate times.

It is not just land use, but also the level of husbandry that is important. More intensive agriculture in the higher (winter) rainfall zones will reduce runoff and deep drainage, as crops and pastures will be healthier and greener for longer periods during the year, thereby increasing the evapotranspiration (ET). Better crop and pasture management is generally highly profitable as shown by leading farmers, but is greatly influenced by climatic risks which requires additional knowledge and management skills. The worsening terms of trade will continue to force Australian farmers to intensify while keeping cost of production down, thus minimising risks of overuse of fertilisers, herbicides and pesticides. Managers have to know what, when and how much to apply to remain profitable and sustainable. The combination of these make agriculture more and more knowledge intensive, the new meaning of intensive agriculture.

Simulation models can be used to analyse how management influences production and water balance across climatic variability within a specific location. The SIMTAG wheat simulation model (9) was used to evaluate historic wheat production in the Wagga Wagga Shire. SIMTAG provides a weather and soil determined reference yield that is attainable (?potential?) for nutrient non-limiting, and disease and weed-free crops. Simulated yield, crop development and water use were validated with best trial results in southern New South Wales by Fischer *et al*. (5) and judged satisfactory for use in the analysis of tillage systems.

This paper presents results of the simulated wheat production and its relationship with Shire yields, sowing date, seasonal rainfall, water use efficiency (WUE) and water balance components.

Methods

Daily weather data of maximum and minimum temperature, solar irradiance and rainfall for 45 years (1949-1994) from Wagga Wagga (35^{o}4?S, 147^{o}21?E, 219 m above m.s.l.) were used in the simulations. Average annual rainfall for this period was 565 mm (190-1058 mm, C.V. 31%) and fairly evenly distributed over the months. A soil water profile for a red-brown earth at Wagga Wagga derived by Fischer *et al.* (5) was used here. It has a plant available water (PAW) of 134 mm over 150 cm of depth. A better soil with a PAW of 180 mm was used to quantify the impact of soil type. Average wheat yields for the Wagga Wagga Shire from the Australian Bureau of Statistics (ABS) were used.

The impact of start of growing season on production and water balance was evaluated by using a range of sowing dates (1 April - 15 July) with appropriate varieties. Continuous wheat was simulated with only soil evaporation occurring between cropping seasons. Thus, the soil water profile at each sowing reflects cropping in the previous season moderated by summer rainfall. New models are being developed to analyse appropriate timing from pasture into cropping based on soil moisture and nitrogen profiles, and weather forecasts (2).

The consequences of poorly managed crops (*eg*. poor nutrition, diseased) were simulated in SIMTAG by introducing a reduction factor on daily leaf expansion which reduced transpiration and shortened the season.

Results and discussion

The average simulated attainable production for normal sowing in mid May was 4.22 t/ha (range 0.9-6.8 t/ha). The average ABS Shire production over the same period was 1.66 t/ha (0.6-3.0 t/ha), which is 39% of simulated attainable yields. The 15-year running average indicates that the percentage of attainable yield has increased at a rate of some 5% per decade, from 30% in the 1950?s to 50% in the 1990?s. Average yield improvement was a steady 26 kg/ha/yr over this period.

Average yield for the simulated poor crops was 1.9 t/ha and was comparable to the Shire yields. Low Shire yields are most likely caused by a combination of low fertility, diseases, late sowing and water logging. The current average yield for a good farmer (B. Hart, *pers. comm*.) was about 80% of attainable, which could be approaching the highest level attainable while remaining profitable, due to uncertainty in weather. Simulated nutrient non-limiting yields can provide a good target yield for farmers without all the complexities of nitrogen dynamics at a paddock scale. Crop monitoring, such as through TOPCROP (1), will allow the diagnosis of observations to help identify factors limiting yield on that paddock.

Timeliness of sowing is important as simulations gave a yield loss of 5% per 1-week delay in sowing of recommended varieties after late April. Kohn and Storrier (8) found grain yields at Wagga Wagga declined by 3.7% per 1-week delay in sowing after late April during the 1960?s. Gomez-Macpherson and Richards (7), working with modern wheats, established for this region a yield loss of 1.3% per day when sowing was delayed after late May. Analysis of some 700 wheat crops in southeastern Australia, stored in a farming systems database, gave an average yield loss of 4% per 1-week delay in sowing after late April with a loss in gross margin of 8 % (M. Stapper, unpublished). These field results confirm the validity of SIMTAG analyses.

Opportunities for early sowing vary with season. The ?break of season? at Wagga Wagga was derived from simulations over the sowing date range across years as the first date at which crops germinate the next day to produce yield. For sowings on 1 April, 15 May and 1 June probabilities of successful germination on the day after sowing were 40%, 72% and 91%, respectively. Sometimes there is a yield loss for early sowing in dry years, but that loss is small compared to big gains in good years. Simulated yield penalties for late sowing were 5 kg/ha/day in dry years, 25 kg/ha/day in average years and 100 kg/ha/day in good years. Seasonal rainfall is still uncertain at sowing, hence the strategy should be to sow closest to the ?break of season?.

Simulated and Shire grain yields are presented against seasonal rainfall from April to October in Fig.1. Commercial crops are closest to simulations, and hence most efficient in water use, in the drier years. Shire yields flatten out when seasonal rainfall exceeds 300 mm. The increasing yield gap with increasing rainfall could be caused by nitrogen stress, diseases and water logging (6). Simulated yield levels off when seasonal rainfall exceeds about 450 mm. This is a function of the size of the ?bucket?, the amount of water that can be stored in the root zone. Additional rain will be lost as deep drainage or runoff (outflow) once the ?bucket? is full in winter when crop water use is low. Research emphasis on drought avoidance and WUE of plants seems misplaced for areas such as Wagga Wagga. Improved crop management can return higher yields and bigger profits with current varieties. Tolerance for diseases and water logging seems more important.

The French-Schultz relationship for yield assessment from seasonal rainfall (6) gave yields between 46 and 200 % of simulated attainable with WUE between 9 and 41 kg/ha/mm. The French-Schultz WUE of 20 kg/ha/mm is shown in Fig. 1 with the intercept changed from 110 to 100 mm to broadly fit the simulated yields. Rainfall pattern and initial soil water content determine the intercept for a given season as a result of differences in soil evaporation, outflow and storage. Average seasonal soil evaporation was 180 mm (81-301 mm) or 44% (25-70%) of seasonal ET. Simulated yields for a seasonal rainfall of around 300 mm were between 1.6 and 4.8 t/ha with no occurrences of outflow. French-Schultz can give a first indication of foregone yield at low farm yields, but will give an unreliable measure when production level improves. Rainfall then has to be replaced by simulated ET with a daily soil water balance to express the seasonal variability and local soil.

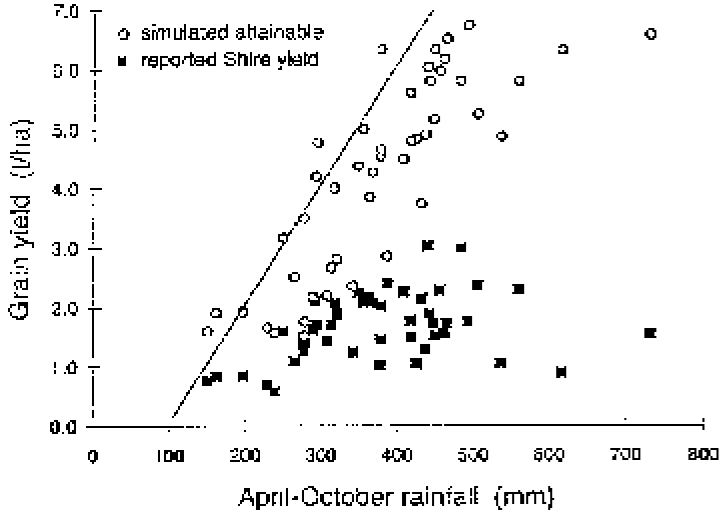

Figure 1. Simulated and Shire annual wheat yields at Wagga Wagga as a function of seasonal rainfall.

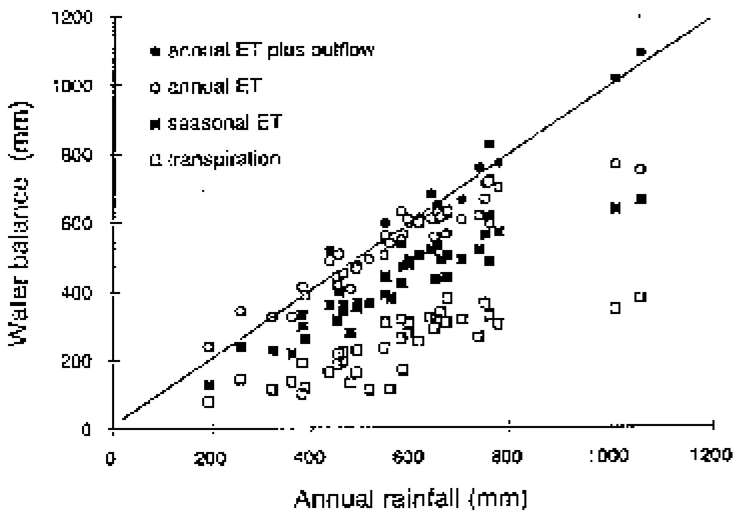

Figure 2. Simulated components of the water balance as a function of annual rainfall for attainable crops.

In this analysis average seasonal ET for normal sowings was 416 and 382 mm for simulated good and poor crops, respectively (C.V. ~30%). This is comparable with the 400 mm ET over the nominal growing season as found in field studies at Wagga Wagga by Dunin and Smith (4). Simulations showed that seasonal ET for good crops is about 75% of annual rainfall (C.V. 11%). Average simulated transpiration was 236 mm (C.V. 37%) for good crops, which is a grain WUE of 18 kg/ha/mm, comparable to the 20 kg/ha/mm used by French-Schultz (Fig. 1). This is another model validation as SIMTAG does not use the transpiration concept, a fixed WUE, to link transpiration and photosynthesis.

Fig. 2 gives water loss components of the water balance against annual rainfall. Transpiration levelled off around 650 mm annual rain. Differences between seasonal ET (April-November) and transpiration or annual ET reflect soil evaporation within season and over summer fallow, respectively. Average simulated annual ET from harvest to harvest was 528 mm (C.V. 23%). The change in soil water storage over the simulated years was negligible. The average annual rainfall of 565 mm, therefore, yielded an average simulated outflow for well managed crops of 37 mm/yr on a red-brown earth. Annual ET plus outflow data above the 1:1 line indicate use of soil water stored in previous year(s), while those below the line increased storage.

Simulated poor crops, which reflect Shire crops, had an average outflow of 62 mm/yr. Outflow occurred in 47% and 65% of years with good and poor crops, respectively. Water loss was dominated by two annual outflows of 314 (1974) and 250 mm (1956) for good crops. Median outflows were 0 and 45 mm with a probability of 10% in exceeding 130 and 160 mm for good and poor crops, respectively. Dunin *et al*. (3) reported a median outflow of 10-25 mm for agricultural systems with an average annual rainfall of 550 mm.

The sensitivity of soil type was simulated by using a better soil, a red earth, with a PAW of 180 mm. Outflow then occurred in 25% and 55% of years for good and poor crops, respectively. The 46 mm extra storage in the root zone of this soil, compared with the standard red-brown earth, decreased the average annual outflow by about 20 mm for both good and poor crops.

Conclusions

SIMTAG can be used to evaluate local production against simulated attainable yields. Diagnostics with crop monitoring will provide information about the most limiting factors in approaching the attainable. Current average Shire production is only 50% of yields achievable under perfect crop management. That percentage appears to be slowly increasing by 5% per decade. Good farmers have reached 80% which is probably near the optimum for financial sustainability. Good management can nearly halve the water lost through deep drainage and runoff and will improve catchment health. Important management factors are timely sowing and keeping the crop green and healthy for the longest possible time. That has to be achieved through proper land use sequences to avoid diseases and optimise fertility with proper year-around husbandry.

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