Conceptual implications for water use of cereals derived from spatial variability in yield maps

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Abstract

A new conceptual framework is proposed for interpretation of yield variability, based on the key processes of 3-D water and nutrient movement in the landscape. This concept extends to a rationale for linking paddock-scale measures to adjacent paddocks and subsequently to catchment scale impacts. Limitations to grain yields often concern available soil-water, which is affected by soil type, weed competition, and incidence of disease, but pests and frost can also affect water use. In this study we investigated the inherent variability of cereal crops in environments representative of SE Australia. Grain yields were mapped on a range of widely different soil types during a single growing season. Maps of wheat, barley and triticale grain yield were obtained from whole paddocks on commercial farms at Nhill, Geelong and Dookie using either commercial-scale headers or hand-harvested samples. Grain yield varied according to soil type and below average growing season rainfall (range 222 to 339 mm). At all locations mapped, some areas within paddocks exceeded potential yield and hence, apparent water use exceeded growing season rainfall. We suggest that water had either redistributed as runoff or lateral flow, or there was a large carryover of stored soil water. These data and others commonly collected by farmers highlight the importance of water redistribution at the sub-paddock scale (whether a deficiency or excess) for cereal yields. Interpretation of yield maps may be improved by a better understanding of water movement and its relationship to rainfall intensity and this approach presents a new challenge for achieving increased productivity and minimisation of offsite environmental hazards.

Keywords

Soil water availability, runoff, lateral flow, yield map, spatial variation, paddock-scale.

Introduction

Traditional agronomic research attempts to quantify the production capability and management practices in the landscape by averaging crop responses across the paddock as a management unit. Typically, an averaged one-dimensional model of water availability is used to determine yield potential. The advent of precision agriculture technology with differential global positioning systems (DGPS) and yield maps offers the potential for within paddock management. If grain yields vary spatially, some areas of the paddock have contributed more and others less in terms of the average level of nutrients and other inputs. Electromagnetic surveys and spatial soil sampling has shown that much of the variation is often associated with soil conditions such as pH, texture, sodicity, salinity or subsoil conditions. However, large variation between seasons has also been found in different environments, and can show opposite effects in successive seasons. Changes in soil water content and redistribution of water during rainfall events depend on soil conditions and rainfall intensity patterns. These variables may account for some of the variation in yield maps, both within and between seasons (1). Without an understanding of these processes the ability to predict yields and hence, spatially manage crops for increased benefits, may be somewhat limited.

The traditional and empirical approach of using seasonal rainfall totals for agronomic determinations of crop yield fulfils a key role for economic comparisons and benchmarking. Closer scrutiny, however, is needed for managing reductions in off-site environmental impacts and to achieve sustainable production systems. Assumptions normally made about key components of the water balance, which includes zero surface runoff, uniform lateral flow and preferential flow through the soil, are based on simple models. Notwithstanding these assumptions, we applied the French and Schultz (2) potential yield approach to benchmark sub-paddock variation in apparent water use (AWU). To achieve a more complete analysis, rainfall data on a daily, hourly or even smaller time interval intensity basis may provide a useful tool for estimating water redistribution from one part of the paddock to another during and shortly after rainfall events. However, in this study we measured crop yield variation at the seasonal level in paddocks across Victoria, where marked differences in soil type and growing season rainfall occurred.

Materials and Methods

Yield maps were taken from whole paddocks located on 4 different soil types representative of cropping regions of Victoria (Table 1). Commercial harvesters were fitted with Agleader? yield mapping equipment and used satellite based DGPS to give sub-meter and real-time spatial coordinates. Mapped yields were calibrated using the total weight of harvested grain measured by weighbridge and erroneous yields greater than 10 t/ha were removed from the data. Yield maps were kriged using a contour software package (Surfer $7^?$). At Geelong and Dookie, grain yields were also obtained from hand harvested quadrats of 1.5 /m^2 taken on a 60 m grid across whole paddocks. Soil types were either Chromosols (Wimmera red-rise, Nhill), Dermosols (red-brown earth, Dookie), Chromosols (brown loam, Dookie) or Sodosols (sand over-lying clay on raised-beds, Geelong) (3).

Apparent water use (AWU; mm) maps were calculated using the French and Schultz (2) approach where AWU = (yield/TE) + SE, where yield is in kg/ha, with TE (kg/ha/mm) the transpiration efficiency and SE (mm) the soil evaporation. A fixed TE of 20 kg/ha/mm was used (2), which meant that any actual lower values of TE would increase the amount of T and hence AWU, and conversely, higher actual TE would reduce AWU. The AWU term encompassed any redistributed water in addition to rainfall and carryover stored soil water. However, even though there may have been differences in soil profile water content, seasonal SE was assumed fixed at 110 mm for wheat and 100 mm for barley. We assumed that relatively uniform surface soil wetness was likely across the paddock under early crop growth stages when ET was low and that in spring, when full crop cover was present and rainfall was infrequent, most soil evaporation would have occurred at the second stage of the process (4), all of which would limit the opportunity for wide variation in SE. Rainfall data was derived from a combination of the Bureau of Meteorology patched point data sets (PPD) (5) and local weather station data.

Results and Discussion

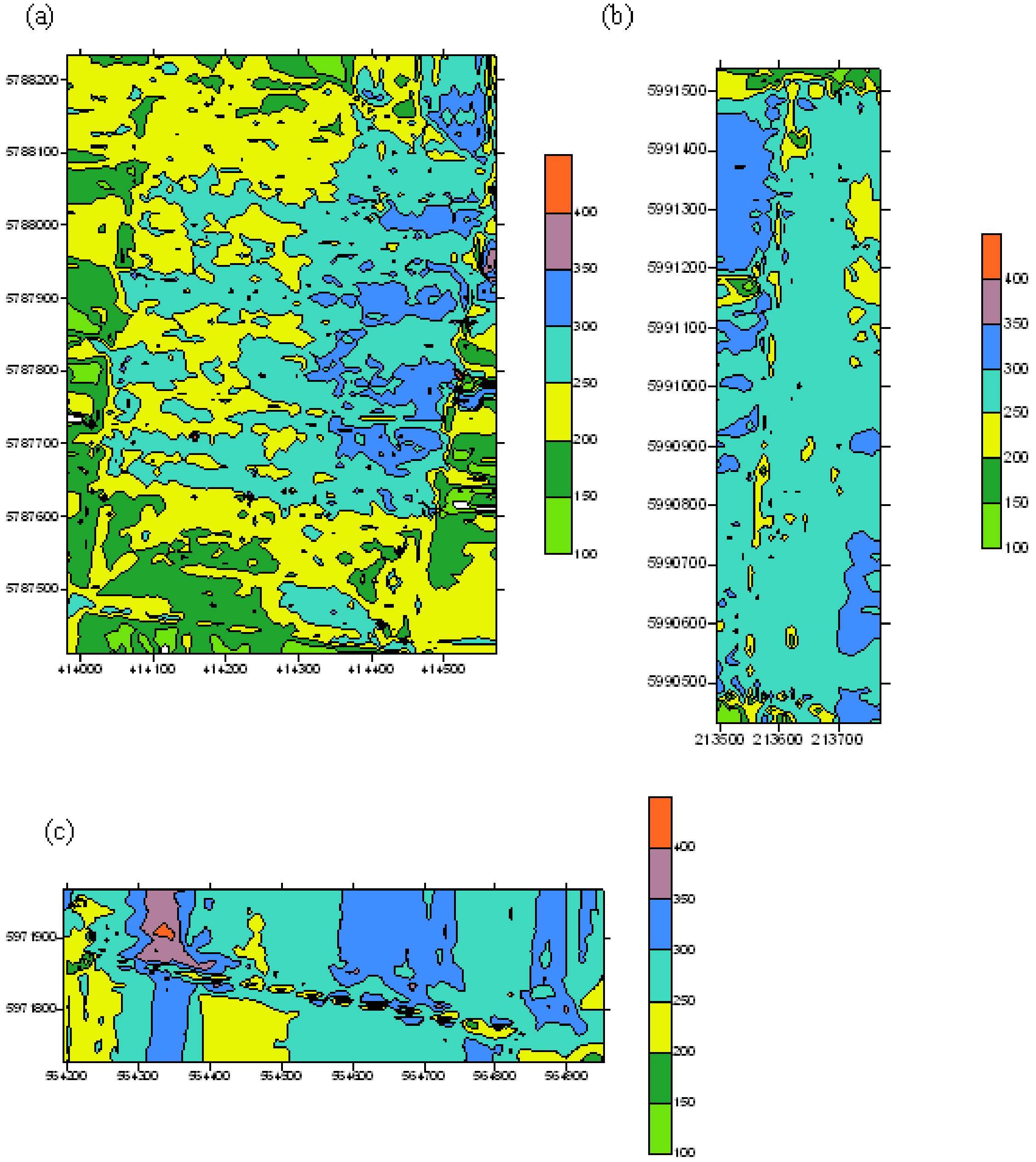
Summer rainfall in 1997 was approximately 50 mm across all the 4 sites and would not have been expected to contribute significantly to overall yield differences within the paddock due to high evaporation over summer. The location of selected paddocks, their annual rainfall, growing season rainfall, crop type and average paddock grain yield (from yield maps) are shown in Table 1. Hand-harvested grain yields were similar to that for harvester yields, with 2.95 t/ha for barley on raised-beds at Teesdale (adjusted from 4.22 t/ha for furrow area) and 3.32 t/ha for paddock C41 at Dookie.

Table 1. Site locations of selected paddocks and corresponding crops, yearly rainfall, growing season rainfall and median grain yield for 1997.

Location	Cereal (cultivar)	Annual Rainfall 1997 (mm)	Growing Season Rainfall 1997 (mm)	Median Grain Yield (t/ha)
Teesdale	Barley (Franklin)	401.1	338.7	2.68
Dookie (C41)	Wheat (Swift)	368.2	267.2	3.18
Dookie (Hays 1)	Wheat (Triller)	368.2	267.2	3.36

Nhill	Wheat (Frame)	296.9	221.6	3.14

Annual rainfall was slightly lower than average in 1997 and surface runoff would only have occurred if soils were wet and rainfall intensity had exceeded the 3-30 mm/hr saturated hydraulic conductivity values typical of these locations and soil types under cropping (6). The variation in AWU shown at all five locations inferred that rainfall intensity exceeded permeability of the surface soil. As summer rainfall was low (less than 50 mm) it is unlikely that high variability in soil water content was carried forward over summer from the previous year. Carryover of soil water from 1996 was possible at Teesdale and Nhill, after a failed canola crop and vetch that was cut for hay, respectively.



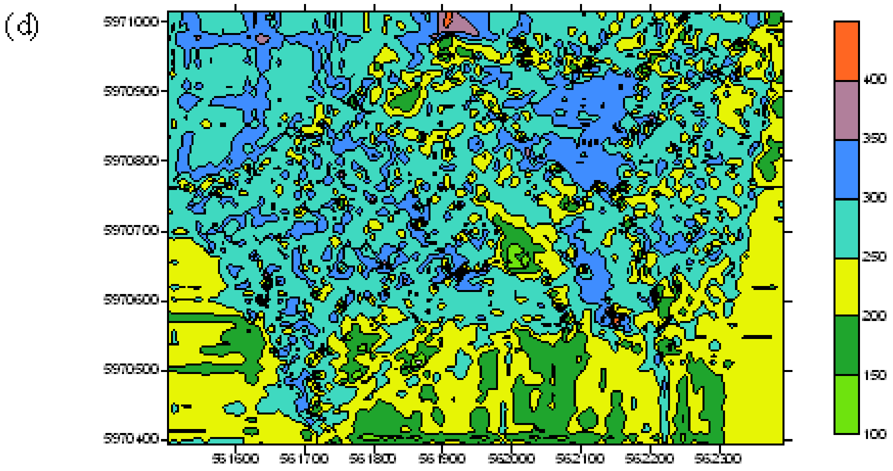


Figure 1. Selected maps of apparent water use (mm) for (a) Teesdale, (b) Nhill, (c) Dookie (Hays 1), and (d) Dookie (C41).

In 1996, the previous season's crops at Dookie were triticale (cv. Tahara) (C41) and wheat (cv. Swift) (Hays 1). Changes in elevation and topography varied from over 30 m in hillslopes (C41 at Dookie) to gently sloping rises of 1-2 m at Teesdale, where impermeable subsoils varied widely across the paddock.

At Geelong, AWU values were similar to GSR on raised-beds that received an application of lime (angular top right of Fig. 1a), and were top-dressed with nitrogen (areas greater than 300 mm), but declined where no beds were present and trees bordered the paddock (left and bottom of Fig. 1a). The high AWU values for wheat achieved at Nhill also occurred over *c*. 25 % of the paddock area, indicative of reliance on stored soil water (Fig. 1b). AWU of wheat cv. Swift in low foothills at Dookie exceeded GSR over *c*. 25 % in the lower areas of the paddock (top of Fig. 1d). Low values of AWU were associated with steep slopes (in excess of 10 % gradient) in the stony upper reaches of the paddock (bottom of Fig 1d). Also at Dookie, high values of AWU were achieved with little evident changes in slope, which suggested that micro-relief in apparently 'flat' paddocks might influence variation in AWU. However, grain yields tended to increase after moderate down slopes and declined in closed depressions (elevation data not shown). As no direct measures of soil water storage or surface runoff were taken, it is not possible to determine the proportion of AWU that increased or decreased due to either redistribution of water or changes in stored water associated with different soil types with a given paddock. Stored soil water and required nutrients would have had to increase substantially to account for the peak AWU and yields measured at the within-paddock scale. There was generally a strong positive relationship between plant biomass and grain yield, except where weeds were present (data not shown).

Differences in management such as, cultivation, grazing history, stubble treatment and rotation may have influenced the hydraulic properties of the surface soil. To control sub-paddock movement of water, some soils may have to be managed with contour cultivation techniques, innovative stubble management or localised drainage to capture rain where it falls and increase AWU. However, concentrating water within productive areas of the paddock may be a way of increasing overall AWU. Increased AWU found at these locations also implied an efficient N supply and reduced losses of N.

Conclusions

The AWU of areas within cereal crops in 1997 exceeded GSR during a season of moderate rainfall, across different soil types and environments. We concluded that the substantial spatial variation in AWU and high values of AWU determined from yield maps across soil types and environments were qualitative evidence for water movement and possible nutrient redistribution at the within paddock-scale. Further paddock-scale research to measure soil water, rainfall intensity and runoff patterns is needed to confirm the degree to which water movement processes contribute to peak crop yields within paddocks and increase AWU. A new conceptual approach to agronomic management based on understanding of processes of water movement may be needed to realise new productivity gains and help minimise the offsite environmental impacts of cropping systems.

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References

(1) Stafford, J.V., Ambler, B., Lark R.M. and. Catt J. 1996. Computers and Electronics in Agric., 14: 101-119.

(2) French, R.J. and Schultz, R.E. 1984. Aust. J. Agic. Res., 35: 743-764.

(3) Isbell, R.F. 1996. The Australian Soil Classification. CSIRO Publishing, Melbourne.

(4) Ritchie, J.T. 1972. Water Resources Res. 8: 1204-1213.

(5) Anon., 2002. The SILO patched point data set. http://www.nrm.qld.gov.au/silo/ppd/PPD_frameset.html

(6) Anon. (2001) Australian Soil Resources Information System. http://audit.ea.gov.au/ANRA/agriculture/docs/national/Agriculture_ASRIS_shc.html.