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Integrating farmer knowledge, precision agriculture tools, and crop simulation modelling to evaluate management options for poor-performing patches in cropping fields

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ABSTRACT

Cropping fields often have poor-performing patches. In an attempt to increase production on poor patches, farmers may apply additional fertiliser or ameliorants without economic or scientific justification. Improved understanding of the extent and causes of poor performance, management options, potential crop yield and economic benefits can give farmers the tools to consider management change. This paper presents an approach to integrating farmer knowledge, precision agriculture tools and crop simulation modelling to evaluate management options for poor-performing patches.

We surveyed nine cropping fields in Western Australia and showed that (1) farmers have good understanding of the spatial extent and rank performance of poor-performing areas, when compared to NDVI or yield maps, (2) there is a wide range of physical and chemical soil constraints to crop yield in such patches, some of which can be ameliorated to raise yield potential, and others where crop inputs such as fertiliser can be better matched to low yield potential.

Management options for poor-performing patches were evaluated through simulation analysis by removal of constraints to rooting to varying extents, and hence plant available water capacity. These examples show that if the constraint is mis-diagnosed then the potential benefits from amelioration can be overstated. In many cases constraints, often associated with physical limitations such as shallow available rooting depth or light-texture cannot be ameliorated or are uneconomic to ameliorate. In such cases the best intervention may be to lower crop inputs to better match the water-limited yield potential of such poor-performing areas.

This research integrated farmer knowledge and spatial data to define yield zones in which targeted soil sampling and crop simulation were then used to determine yield potential and particular constraints to that potential. The economic costs and benefits of differential zone management were examined under a range of husbandry scenarios and, importantly, the sensitivity of economic gain to mis-diagnosis or errors in defining the zones was tested. This approach provided farmers with a robust and credible method for making decisions about spatial management of their fields.

1. Introduction

Cropping fields in the Western Australia (WA) wheatbelt are often large (50–200 ha) with significant spatially heterogeneous soils, crop performance and by inference, profit. Farmers have knowledge of the location of poor-performing patches within their fields, but rarely understand the spatial extent of patches or the basis for poor performance. In an attempt to increase production on poor patches, farmers may apply additional fertiliser or ameliorants without economic or scientific justification. Improved understanding of the extent and causes of poor performance, management options, potential crop yield and economic benefits can give farmers the tools to consider management change.

In Western agriculture there is increasing availability of information on spatial variation in soil and crop performance via yield mapping, soil survey and remote sensing (Cook and Bramley, 1998; Corwin and Lesch, 2003; Godwin and Miller, 2003; McBratney et al., 2005). Knowledge of the distribution and identification of crop yield, soil type and plant available water capacity (PAWC) allows exploitation of the spatial variation for site specific management (nutrient, ameliorant, cropping system change, etc.) (Sadler and Russell, 1997; Adams et al., 2000; Wong et al., 2001; Zhang et al., 2002; Koch et al., 2004; Robertson et al., 2007). There have been only a few studies that have assessed the degree to which spatial

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information supplements farmers' own knowledge of the location of poor-performing patches (Fleming et al., 1999, 2000; Booltink et al., 2001; Wong et al., 2008). The ability of farmers to define management zones that match crop performance has been tested by matching the ranking of measured yields in these zones (Fleming et al., 2000; Khosla et al., 2002; Hornung et al., 2006). However, there has been little analysis of the cost in financial terms of errors in definition of patch (or zone) boundaries when considered in a zone management context. The zone definition can be inaccurate (due to lack of knowledge or techniques to identify zones) or imprecise (due to logistical considerations relating to location and size of zone which can be managed variably by the farmer and farmer's machinery).

While locating the position and extent of poor-performing patches may be straightforward for many farmers with detailed historical knowledge of their fields, the diagnosis of the causes of yield constraints is more complicated. In Western Australia, causes of poor performance can be linked to low soil plant available water capacity (PAWC) (Tennant and Hall, 2001). PAWC is one of the main drivers of yield potential variation in Mediterranean environments and the relationship is seasonally dependent (Mulla et al., 1992; Morgan et al., 2003; Oliver et al., 2006). PAWC is the difference between the drained upper limit (DUL), or water holding capacity after drainage has ceased, and the crop lower limit (CLL) which is determined by the tightness with which water is held within the soil matrix and the crop's ability to extract that water to crop rooting depth. Soil type (clay content, structure) affects the DUL as it determines the water holding capacity of the soil, while soil type, soil depth and chemical constraints will affect the ability of the crop to grow roots to depth and extract water. With knowledge of the soil type and crop rooting depth, the PAWC can be estimated. Spatial variation in PAWC has been linked to variation in crop yield in under high fertility conditions, Mediterranean winter dominant rainfall for winter wheat in Western Australian soils (Oliver et al., 2006; Wong and Asseng, 2006), and in mid west USA (Mulla et al., 1992; Morgan et al., 2003).

Low PAWC, in turn, has been linked to soil constraints that limit crop production, acting through reduced rooting depth and increased CLL. Soil constraints commonly encountered in WA are compaction and acidity of a plough plan layer at 0.2–0.3 m and acidity to depth (Tennant et al., 1992; Hamza and Anderson, 2003; Davies et al., 2006), water logging (Belford et al., 1992; Tennant et al., 1992), salinity (George et al., 1997; McFarlane and Williamson, 2002), water repellent topsoils (Blackwell, 1993; Harper and Gilkes, 1994) and sodic soils (Cochrane et al., 1994).

Once the underlying cause of poor crop performance has been identified it is necessary to consider a range of management responses (including doing nothing), accounting for seasonal variation on the effect of any management intervention, and the economic return. In WA grain-growing systems, management responses may include reducing the level of crop inputs (such as fertiliser or plant density) to match yield potential, application of ameliorants such as lime or gypsum to overcome soil chemo-physical constraints, or deep ripping to modify compacted layers.

Simulation modelling has been used to assess the potential payoffs to such interventions (Asseng et al., 1998; Wong and Asseng, 2007). In such cases the effect of a subsoil constraint like compaction, acidity or shallow depth to bedrock is simulated by using a root hospitality factor to adjust the rate of root depth extension according to the severity of the subsoil constraint (Asseng et al., 1998; Wong and Asseng, 2007) or adjustment to the crop lower limit (and therefore PAWC) (Sadras et al., 2003; Hochman et al., 2004, 2007). However, such adjustments in simulation models are often subjective because they depend on the effect of the constraints on root growth and the severity of the constraint.

With farmers at workshops and field days in the low-medium rainfall zone (200–400 mm) of the Western Australian wheatbelt we have trialled a four-stage approach to identify the location, causes and management options for poor-performing areas of a field. The approach combines farmer knowledge with precision agriculture's spatial data and soil diagnosis. Integrating farmer knowledge with other spatial data may be able to reduce cost of data collection and analysis and also improve communication with farmers. Modelling is used to quantify yield potential as well as the yield gains and financial benefits of amelioration, particularly in relation to increasing soil rooting depth and soil PAWC. Accordingly, the aims of this paper are to: (1) describe the process used, (2) analyse the sensitivity of various aspects of the process to variation in assumptions, and (3) highlight where understanding derived through use of scientific tools and analysis can supplement farmer knowledge.

2. Methods

2.1. Locations in Western Australia

The studies were conducted with four farmers in two grain-growing regions of the Western Australian wheatbelt, which receive between 300 and 400 mm long-term mean annual rainfall. Kellerberrin is in the central wheatbelt of Western Australia, between 30.8° and 32.3°S and 116.7° and 118.6°E, with typically texture contrast (duplex) soils of sand or loams over clay (Luvisols and Lixisols), sands over gravels (Ferralsols) and sand (Arenosols) (Schoknecht, 2002; FAO, 1998). Buntine is in the Northern Agriculture Region which lies between 28.3° and 30.7°S and 114.7° and 116.8°E. Soils are deep, well drained sands (Arenosols), yellow sandy loams and loamy sands (Lixisols and Ferralsols) and loams over clay duplex soils (Luvisol and Ferralsol) (Schoknecht, 2002; FAO, 1998). Both regions are in a mixed cropping zone with cropping sequences based on spring wheat (*Triticum aestivum* L.) in rotation with barley (*Hordeum vulgare* L.), grain lupins (*Lupinus angustifolius* L.), canola (*Brassica napus* L.) and sometimes annual pasture. Typical farm wheat yields in both regions are between 1 and 3 t/ha.

In each location, farmers identified fields on their farms that were known to have obvious spatially variable crop yield. In total 9 fields were analysed, one field each from the two farmers in Buntine and seven fields from the two Kellerberrin farmers, and these varied in area from 39 to 244 ha (Table 1).

2.2. The process

1. Determine the location of different performing areas.
2. Define soil properties and constraints to production.
3. Estimate yield potential with and without constraints.
4. Determine the benefits to management change.

At each stage of the process, the effect of wrongly estimating each component is also determined.

2.2.1. Location of poor-performing patches

Farmers were asked to define the boundaries of zones within the field that had distinctly different soil types and performance. Initially soil maps were drawn and then these soil types were allocated to an above-, at- or below-average performance for the field. A farm boundary map or an aerial photograph was often used as the background for these maps (an aerial photograph could be easily obtained from Google Earth$^{®}$) while the farmers had a range of prior knowledge of the field. The information from the farmers was entered into GIS as polygon layers and converted to a 25 m grid. Spatial correlations were conducted between farmer-identified zones and those identified via "objective" spatial data