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Identifying the spatial and temporal variability of economic opportunity costs to promote the adoption of alternative land uses in grain growing agricultural areas: An Australian example

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ABSTRACT

Grain growers face many future challenges requiring them to adapt their land uses to changing economic, social and environmental conditions. To understand where to make on ground changes without significant negative financial repercussions, high resolution information on income generation over time is required.

We propose a methodology which utilises high resolution yield data collected with precision agriculture (PA) technology, gross margin financial analysis and a temporal standardisation technique to highlight the spatial and temporal consistency of farm income.

On three neighbouring farms in Western Australia, we found non-linear relationships between income and area. Spatio-temporal analysis on one farm over varying seasons found that between 37 and 49% (1082–1433 ha) of cropping area consistently produced above the selected income thresholds and 43–32% (936–1257 ha) regularly produced below selected thresholds. Around 20% of area showed inconsistent temporal variation in income generation. Income estimated from these areas represents the income forgone if a land use change is undertaken (the economic opportunity cost) and the average costs varied spatially from $190 ± 114/ha to $560 ± 108/ha depending on what scenario was chosen.

The interaction over space and time showed the clustering of areas with similar values at a resolution where growers make input decisions. This new evidence suggests that farm area could be managed with two strategies: (a) one that maximises grain output using PA management in temporally stable areas which generate moderate to high income returns and (b) one that proposes land use change in low and inconsistent income returning areas where the financial returns from an alternative land use may be comparable. The adoption of these strategies can help growers meet the demand for agricultural output and offer income diversity and adaptive capacity to deal with the future challenges to agricultural production.

1. Introduction

An increasing world population and changes in diet preferences mean that the demand for agricultural production is expected to rise (Maye and Kirwan, 2013; Hanjra and Qureshi, 2010). However, the limited amount of arable land that holds traditional agriculture is in constant competition with demands for alternative land uses, such as urban development, carbon sequestration, bioenergy and biodiversity conservation (Aertsens et al., 2013; Erb et al., 2012; George et al., 2012; Smith et al., 2012). These issues, factored in with community concern for the impacts of agriculture practices on the environment and the threats from local and global environmental problems, challenge the continued supply of agricultural products (Lawrence et al., 2013; Tscharntke et al., 2012; Wheeler and von Braun, 2013).

To adapt, contest and conform to these challenges, growers will need to balance an allocation of farm land to both traditional and new land uses. For example, land for biodiversity conservation must be large enough to sustain and connect flora and fauna populations across the farming landscape (Arponen et al., 2013; Sherren et al., 2012). Remediation of local environmental issues

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requires mitigation strategies to be allocated to source areas (Ghebremichael et al., 2013; Roberts et al., 2009). While future changes in global climate caused by increased carbon dioxide levels mean that the impact on crops like wheat (Eitzinger et al., 2013; Potgieter et al., 2013; Wilcox and Makowski, 2014) and potential adaptation strategies (Browne et al., 2013; Bryan et al., 2010; Finlayson et al., 2012; George et al., 2012) will depend on the range of climatic gradients and soil types, particularly those which are less conducive to cropping.

A major hurdle in the land allocation process is the spatial and temporal quantification of the loss in financial returns or the economic opportunity cost associated with this change (Adams et al., 2010; Dorrough et al., 2008). Change will likely occur in areas where profit from traditional agriculture is comparable to that of the proposed alternatives (Lefroy et al., 2005). This may occur in areas where the whole agricultural practice is marginal (Dorrough and Moxham, 2005; Maraseni and Dargusch, 2008) or where farms have diminishing financial returns to area (Groeneveld, 2005) caused by cropping unproductive or environmentally degraded soil types (House et al., 2008; John et al., 2005; O'Connell et al., 2006). Past research creating economic returns from traditional agriculture and comparing them with those from more environmentally friendly alternatives (Skop and Schou, 1999; Naidoo and Adamowicz, 2006; Naidoo and Ricketts, 2006; Groot et al., 2007; Barton et al., 2009; House et al., 2008; Crossman and Bryan, 2009; Bryan et al., 2011) has been valuable, informing government authorities of the potential for land use change at the landscape scale. However, the coarseness of the spatial resolution and/or the lack of temporal currency of the economic information used in estimating these opportunity costs provide limited value to growers whose land use decisions are made at the field and subfield scale.

Growers therefore, need an information set created at an appropriate resolution to increase their awareness of spatial and temporal variation in their farm's production. Precision agriculture technology provides a way to increase the knowledge of sub-field production variability and the adoption of this technology has been increasing in Northern Europe, USA, Australia and Latin America for over 20 years (Lawson et al., 2011; Reichardt and Jurgens, 2009; Robertson et al., 2012). The technology allows for management of in-field spatial and temporal variability and can reduce input costs and environmental impacts (Reichardt and Jurgens, 2009). Various studies hypothesise the use of temporal and spatial precision based on production or land quality to inform land use decisions. Temporal precision utilises seasonal climate forecasts from which farm management decisions can be made (Calanca et al., 2011; Marshall et al., 2011). Based on these forecasts and the grower's expectation for the season, a movement is made away from a constant application of inputs across all fields to a strategy of spatial precision within each field. Here, machinery equipped with precision agriculture technology is used to apply inputs to match spatially variable yield potential to maximise yield production and reduce inefficiencies and nutrient losses (Hochman et al., 2013; Diacono et al., 2013). Early studies (Blackmore et al., 2003; Joernsgaard and Halmoe, 2003) showed no apparent yield stability while more recent studies have demonstrated the temporal stability of yield over time and the benefits of undertaking this type of management strategy (Jaynes et al., 2005; Cox and Gerard, 2007; Robertson et al., 2008; Milne et al., 2012). While these studies tend to focus on only a handful of fields, their results provide evidence that low and high producing areas can be managed more precisely.

Identification of the degree of spatial and temporal stability of production also offers an opportunity to allocate land to more environmentally friendly land uses. This is particularly the case in low producing areas where significant negative financial consequences of a change in land use to the farm business can be minimised (Lyle and Ostendorf, 2011; McConnell and Burger, 2011). However, these poor performing areas have been reported to be both small in area and randomly distributed, suggesting their potential reassignment for alternative benefits such as enhance biodiversity conservation or ecological value would not be significant (Lawes and Dodd, 2009). This demonstrates that small areas which produce negative financial returns will have to be combined with those that produce positive financial returns if the benefits of land use change are to be significant.

The aim of this paper is to understand the potential of yield mapping technology to quantify the degree of spatial and temporal variation of farm income at a sub-field resolution at the farm scale. The amount of variation present over time will determine whether spatially precise management strategies can be implemented to address the future challenges on agriculture.

2. Methods

2.1. The study area

The study area encompasses three neighbouring farms within an area of about 14 million hectares (ha) in the Western Australian wheatbelt. These farms were early adopters of yield mapping technology and cropped areas of 2924 ha (ha) (Farm 1), 2000 ha (Farm 2) and 2500 ha (Farm 3) (Fig. 1). The region itself, is characterised by a Mediterranean climate, with cool wet winters and hot dry summers. Over half of the annual rainfall (300–400 mm) occurs between May and September. Table 1 reports the rainfall amounts (March to November) for each year used in the study period. The agricultural landscape is predominately broad sand plains with very little elevation and salty lands situated in the lower parts of the landscape. Cropping rotations are dominated by wheat with lupins and canola used as a break crop while cattle and sheep grazing are also common to a lesser extent on rotation pastures. Broad land clearing for agriculture has mean that only small amounts of randomly scattered stands of remnant native vegetation remain which consist of a mixture of evergreen shrubs and trees that are well adapted to the hot dry summers (Turner and Asseng, 2005).

2.2. Pre-processing of yield mapping datasets

Yield mapping is a precision agriculture technology tool that involves the combine harvester being fitted with a global positioning system and a grain flow measuring device. As the combine harvests, the grain yield and current position are recorded with a high accuracy of measurement at between 1 and 3 s (Birrell et al., 1996; Arslan and Colvin, 2002). The two-dimensional mapping of this data identifies the magnitude of spatial yield variability and its association with financial data can depict areas of differing profitability (Massey et al., 2008).

Different rates of adoption of yield mapping technology are evident across the Australian farming landscape (Jochinke et al., 2007) and this was also apparent in our study area. In order to test our methodology we selected early adopter farms where yield mapping data varied from eight years for Farm 1 to five and six years of data for Farms 2 and 3. Yield data for wheat, the predominate crop type farmed, was collected using three different combine mounted yield monitors across the three farms. For simplicity, break crops were excluded because of their comparative small planting numbers and different cost-price structures. Data collected in drought years (2000 and 2002) were removed as extremely low yield values (close to zero) were recorded. We