The integration and validation of precision management tools in mixed farming systems.

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Abstract
Precision farming techniques are now widely applied within simple cropping systems. However the use of precision technologies to improve the production efficiency of pasture phases in mixed farming systems remains largely unexplored. This paper reports on a project that is examining the agronomic and financial outcomes of using remote and proximally sensed data and site specific management strategies on the sustainability, resilience and profitability of dryland mixed farming systems. Experimental data are being gathered from two dryland cropping sites, one in Western Australia and one in north-eastern Victoria. Remote sensing technologies are being used to investigate livestock and pasture interactions in the grazing phase and to follow the after-effects of different management strategies into a subsequent cropping phase. Although the project is still in an early phase, results generated to date using relatively coarse NDVI (250 m pixel) data from MODIS satellite imagery as an indicator of net primary production suggest that spatial variation in biomass between pasture and cropping phases is consistent and correlated over time. Higher resolution analysis at the 1m-10 m pixel scale is required to enable further exploration of the relationships between the pasture and cropping phases.

Key Words
Spatio-temporal analysis, accumulated NDVI, precision agriculture technologies, correlation of spatial variation, pasture/crop rotations.

Introduction
The suite of precision management technologies currently available to agriculture is used principally by grain producers to manage crops, and by some grazing enterprises to manage pastures, e.g. Pastures from Space (Edirisinghe et al., 2004; Edirisinghe et al., 2011). Despite the proven utility of precision farming techniques in cropping, there appear to have been few attempts to use spatial monitoring technologies to investigate interactions between the pasture phase and subsequent cropping phase on overall productivity of pasture-crop systems. Although collecting remotely-sensed raw data is a comparatively simple task, selecting the correct tools and methods for data analysis and subsequent decision making is a challenge, particularly when applied to mixed farming systems. A recent survey of Western Australian farmers indicated that data analysis and complexity was one of the greatest impediments to the adoption of precision agriculture (PA) (Robertson et al., 2012). The pasture-livestock phase provides flexibility to farm management, an opportunity to manage risk, build soil organic matter content, supply nutrients and manage crop diseases and herbicide resistant weeds (Fisher et al., 2010). For the most part, pasture paddocks tend to be managed as single units, ignoring the existence of productivity gradients across the landscape (Hill et al., 1999). As a consequence, the uniform application of inputs to pastures may result in economic losses and contribute to environmental degradation (Chen et al., 2009). Pasture “zone maps” that can identify how pasture yields are spatially distributed, could allow poor performing areas to be identified for site specific management such as selection of pasture cultivars or variable rate application of nutrients, which could have flow-on benefits into the cropping phase.

This paper reports on the initial results of investigations using relatively coarse-resolution (250 m pixel size) spatial data from the Moderate Resolution Imaging Spectroradiometer (MODIS) normalised difference vegetation index (NDVI) product (Justice et al., 2002; Tucker, 1979). NDVI is strongly related to leaf area index of green herbage during the vegetative growth of annual cereal or pasture species (Smith et al., 2011). In this study, accumulative NDVI is used as a measure of net primary production (Gower et al., 1999) to determine if any relationship exists at the sub-paddock scale, between biomass production in the pasture phases and cropping phases of a mixed farming system.

Methods

Study sites

Experimental data were gathered on two properties: “Milroy”, a 1900 ha sheep and cropping enterprise located at Brookton, 120 km east of Perth, WA (32.22°S, 116.57°E) and at “Grandview”, a 2250 ha cattle and cropping enterprise located 10 km south of Yarrawonga, (36.05°S, 145.60°E) in north-eastern Victoria. On both properties the main crops grown are wheat and canola (Table 1). On each property, paddocks were identified that had been in a pasture phase within the past three years. Pastures at Brookton are predominantly self-sown, comprising sub-clover (*Trifolium subterraneum*), serradella (*Ornithopus spp.*), barley grass (*Hordeum glaucum*) and capeweed (*Arctotheca calendula*). Pastures at Yarrawonga contain lucerne (*Medicago sativa*) and sub-clover (*Trifolium subterraneum*). At least five years of data from harvest yield monitors was available for each paddock.

Table 1. Crop rotations and growing season rainfall (GSR) or annual rainfall data (mm) for the Brookton and Yarrawonga sites.

	2003	2004	2005	2006	2007	2008	2009	2010	2011
Brookton M45 Rotation	-	wheat	lupin	pasture	canola	wheat	pasture	wheat	pasture
Brookton GSR	334.9	263.9	428.4	227.9	370.1	416.3	327.7	161.7	330.8
Yarrawonga GV40 Rotation	wheat	barley	pasture	pasture	pasture	pasture	pasture	wheat	wheat
Yarrawonga GSR(mm)	394.5	260	333.5	148	190	155	245	406.5	242.5
Yarrawonga annual RF(mm)	538.5	365	567.5	217	355	334	293	794	687.5

Weekly satellite data

Weekly MODIS NDVI data for the study paddocks over the period from 2004 to 2011 were provided by Landgate. It was acquired from daily MODIS satellite imagery from the AQUA and TERRA satellites composited to provide one single maximum NDVI image each week. MODIS images have a ground resolution of approximately 250 m^2 with an ortho-rectification accuracy of approximately ±50 m (Smith et al., 2011). MODIS pixels that lay entirely within the study paddock boundaries were identified from MODIS imagery. For these pixels, the accumulated annual NDVI was derived by summing the weekly NDVI values over each year. The accumulated weekly MODIS NDVI pixel values for each paddock pixel were then used in a correlation analysis using the JMP 9 software package (SAS Institute Inc, Cary, North Carolina) to determine if relationships existed between pasture and crop biomass production over the nine years for which data were available.

Results and Discussion

Figure 1 shows an example of pair-wise correlations of accumulated weekly MODIS NDVI pixel values for each year and Pearson correlation co-efficients (r-values) using data from Brookton paddock M45. The higher the r-value, the stronger the correlation. In this paddock, all cropping years showed strong correlation of cumulative weekly NDVI for individual pixels. This indicates that high biomass areas (6.25 ha pixels) were consistently high over time and poorer performing areas consistently poor. There is a similar pattern when comparing years in which the paddock was in pasture. When comparing crop years with pasture years, the correlation matrix gave a lowest Pearson correlation co-efficient (r = 0.53) between the 2006 (pasture) and 2008 (crop) years to a high (r = 0.98) between the 2005 (crop) and 2009 (pasture) years. The 2006 season had extremely low rainfall in WA.

At the Yarrawonga site, pair-wise correlations for accumulated annual NDVI for paddock GV40 (not shown), between the cropping years 2010 and 2011 was reasonably strong, but poor between the 2004 and 2010 cropping years and between the 2004 and 2011 cropping years. For the period in which the paddock was in pasture, the years 2005-2007 showed strong inter-year correlations for accumulated NDVI, with r values ranging between 0.7 and 0.89. Inter-year correlations between the 2007, 2008 and 2009 pastures were negative. The cause of this is not clear at this stage and requires further investigation. It is noteworthy that the period 2007-2009 included three of the four lowest rainfall periods in the nine year series and this may have had an influence. Inter-year crop/pasture pair-wise comparisons were not as consistent as at the Brookton site, ranging from a negative r value (-0.84) between 2007 (pasture) and 2010 (crop) years, to an r value of 0.76 between the 2004 (crop) and 2005 (pasture) years. The very poor rainfall between 2006 and 2009 may have adversely influenced the 2007-2010 correlations.

Although relatively coarse resolution data have been used in this initial study, the results indicate that there is a definite relationship between spatial variation in biomass production in the cropping and pasture phases over time. These relationships appear to hold for both annual pastures (Brookton study site) and perennial pastures (Yarrawonga study site). The responses of perennial pastures to seasonal climatic conditions present a more complex situation as they do not exhibit the distinct beginning and end of season that characterises annual pastures.

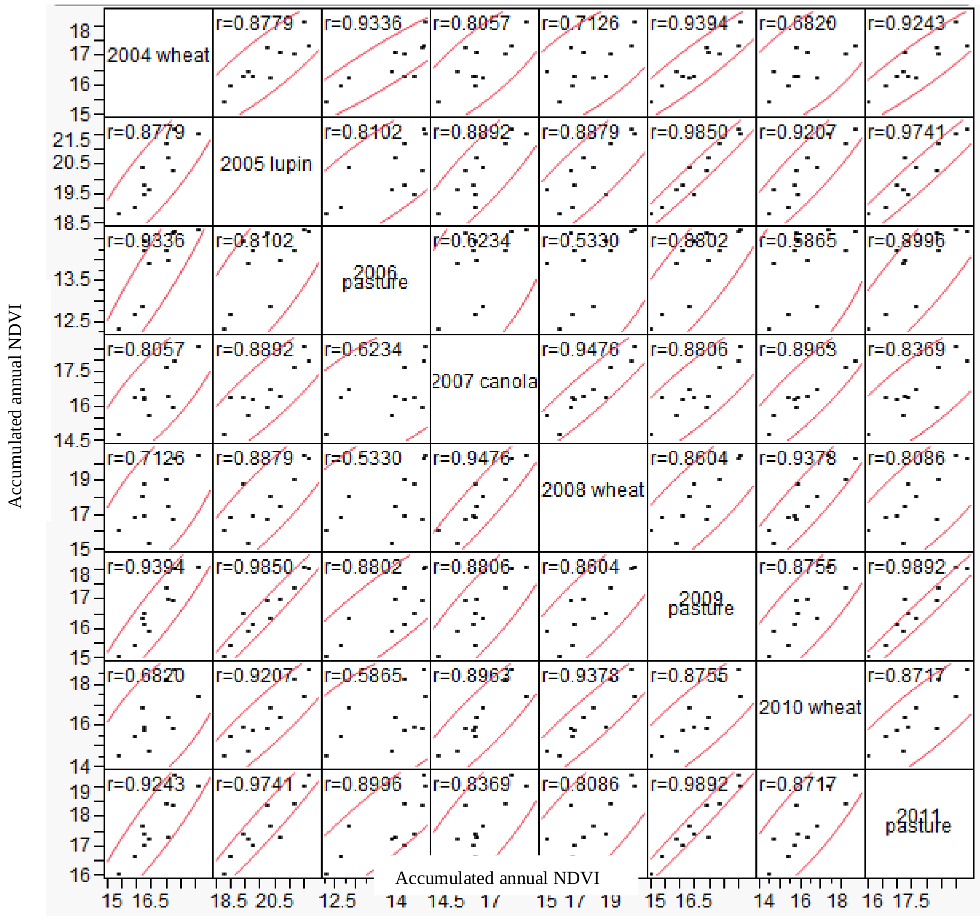

Figure 1. Pairwise scatterplots showing Pearson correlation coefficients (r) between accumulated weekly MODIS NDVI pixel values for each year over the period 2004 – 2011 for Brookton paddock M45. For example, the correlation co-efficient (r) between 2004(crop) and 2006(pasture) is 0.9336 (an r value of 1.0 implies perfect correlation). The density ellipses (red lines) enclose approximately 95% of the points (ie α = 0.95).

Further exploration is required at a higher spatial resolution to investigate within-paddock pasture biomass production, crop yield and pasture species composition changes over time and will form the next phase of this project. An active optical sensor will be used to acquire red and near infra-red (NIR) reflectance values to produce much higher resolution NDVI data, which can be related to pasture biomass (Trotter et al., 2010; Trotter et al., 2008). These data could then be used in combination with harvester yield-monitor data and soil texture information from electromagnetic induction (EM38) surveys to allow high resolution analysis (1m-10 m pixels) to inform the low cost, coarser resolution MODIS data. This analysis could also be used to inform the reliability of MODIS pixels to represent whole-paddock biomass production estimates as provided by Pasture Watch^{TM} (Fairport Farm Software, Perth, WA), or sub-MODIS pixel refinements to pasture/crop management.

Conclusion

It is very encouraging that even with low resolution imaging it was observed that there were significant correlations in spatial variation of biomass production between crop and pasture phases in mixed farming systems, for both annual and perennial pasture systems. This suggests that higher resolution data derived from precision agriculture tools such as active optical sensors, harvester yield monitors and electromagnetic induction sensors may add significant interpretive value to analysing within paddock variability, especially given the spatial heterogeneity of pastures. The use of precision technologies to further investigate the correlation of spatial patterns between pasture and cropping phases has the potential to provide new insights into the impact of managing temporal and spatial variability in livestock grazing systems and the impact on the subsequent cropping rotation.

Acknowledgements

This work is supported by funding from the Grains Research and Development Corporation (GRDC) and Curtin University. Peter McEntee is also supported by the Future Farm Industries CRC Postgraduate Professional Development Program. The authors gratefully acknowledge the valuable assistance of Richard Stovold and Norm Santich of Landgate WA, in providing weekly MODIS satellite data and related advice and Roger Wiese from Fairport Farm Software for provision of software and technical support. We also thank the landholders, Murray Hall (Brookton) and Adam Inchbold (Yarrawonga) for their advice, patience, cooperation and assistance.

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