Using high resolution landscape and soils data to understand spatiotemporal variability in net pasture productivity as derived from low spatial resolution remote sensing.

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Abstract

Spatial variability in pasture production, especially at within-field scales challenges land managers seeking to optimise management to increase the overall productivity of their grazing operations. In this study, a relatively coarse, remote, spatial-based measure of net primary production on a farming landscape of predominately tall fescue (*Festuca arundinacea*) pasture was derived using accumulative NDVI from weekly MODIS satellite imagery. This data was evaluated against two, higher spatial resolution, on-ground descriptors often linked with productivity; namely soil texture, via a electromagnetic induction instrument (EM38) and elevation data. Net primary production was observed to be larger within the lower slopes and valley floors of paddocks; the same areas most likely associated with higher levels of long term soil moisture. The implications of using relatively low spatial resolution remote sensing products (100-200 m) to monitor and forecast pasture production, and avenues for increasing the spatial resolution of such products using third-party, on-ground datasets like EM38 are also discussed.

Introduction

In temperate and Mediterranean regions of Australia, pasture utilisation by grazing animals is often as low as thirty percent (Thompson et al*.* 1994). Feed budgeting and stocking rate adjustments at the farm and paddock scale are an important response to improving feed utilisation. Pastures from Space™ is an example of a remote sensing-based pasture evaluation and monitoring program designed to improve feed budgeting and resource allocation. This remote approach allows estimates of pasture growth rate (PGR) and feed on offer (FOO) to be made from satellite imaging (Edirisinghe et al. 2000, Edrisinghe et al. 2010, Hill et al*.* 2004, Donald et al*.* 2004, Donald et al*.* 2010 and Smith et al*.* 2010). Both PGR and FOO are derived from the normalised difference vegetation index (NDVI) which is strongly related to leaf area index of green herbage (Edirisinghe et al. 2000), and in some cases can be directly calibrated as a measure of pasture biomass (Trotter et al. 2010). However, the spatial resolution of the Pastures from Space product is limited to that of the source data. Currently the source data is acquired from the Moderate Resolution Imaging Spectroradiometer (MODIS) satellite borne sensor and provides a resolution of approximately 250m^2.

As precision agricultural continues to grow its use in agriculture there is a potential mismatch between the spatial resolution from MODIS, and harvester based yield maps and electromagnetic induction sensor surveys such as EM38 surveys which are use to identify soil differences particularly differences in water holding capacity (Hossain et al*.* 2010). Yield map and EM38 based data can be subsequently used at sowing to apply real time variable rate applications of seed and fertiliser at a much high resolution than MODIS data allows. To overcome some of these MODIS limitations high spatial resolution digital elevation data can be accessed from a range of sources (e.g. LIDAR) and integrated with other sources to offer improved insights to micro-topographical constraints of biomass production (for example Kitchen et al. 2003).

In this study we will examine the interpretative value of including high resolution EM38 and elevation data with the relatively coarse spatial resolution NDVI acquired from weekly MODIS imagery of a 240 ha farming landscape during a single pasture growing season. Here the accumulative NDVI will be used as a measure of net primary production (Gower et al*.* 1999).

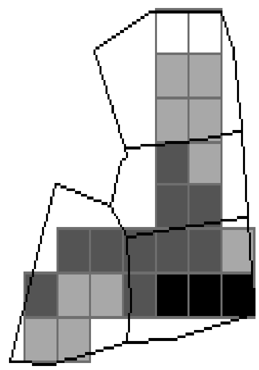
Materials and Methods

Study Site

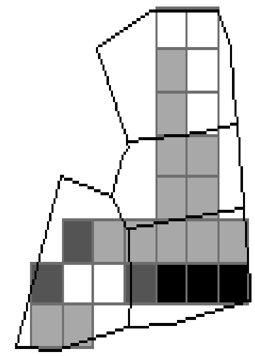
The study site, located in northeast New South Wales (29°47'S 151°21'E) consists of rolling hills (undulating) with perennial pastures bordered by heavy scrub and perennial woody vegetation. It has a predominately southern aspect with an average yearly rainfall of 770mm of which 65% falls between October and March. The study site comprised of four paddocks of approximately 60ha in size sown to tall fescue (*Festuca arundinace*). Stock was rotated during the 2008-9 growing season (mid-winter to summer) in an attempt to maintain biomass levels at approximately 1000 kg/ha dry matter.

(a) EM38 survey

(b) Elevation



(c) Accumulated NDVI for 2008 for selected MODIS pixels



(d) Accumulated NDVI for 2009 for selected MODIS pixels

Figure 1. Target area data for EM38 survey, elevation and accumulated NDVI (2008 and 2009) for selected MODIS pixels.

Weekly satellite data

Weekly MODIS satellite NDVI images were acquired for the 2008-9 growing season using daily imagery acquired from the AQUA and TERRA satellites. The daily NDVI images were subsequently composited to provide one single maximum NDVI image each week. The images had a ground resolution of approx. $250m^2$ and have an ortho-rectification accuracy of approximately ?50m (Smith et al. 2010). The accumulated NDVI was derived by summing the weekly NDVI images over 2008 (Figure 1(c)) and for 2009 (Figure 1(d)).

EM38 Measurements

Measurements of apparent soil electrical conductivity ($EC_{a,}$ mS/m) were completed using a Geonics EM-38RT unit (Geonics Ontario, Canada) operated in vertical dipole mode and towed behind an all-terrain vehicle (ATV) on a rubber sled (Lamb et al. 2005). The continuous output data stream from the EM-38 unit was fed into a Trimble TSCe data-logger along with the 1 Hz DGPS location information from a differential global positioning system (DGPS) (Trimble, Sunnyvale California, USA) resulting in a data array of approximately ~2m point-to-point spacing on ~40m transects using the protocol describe by Schneider et al. (2009). The survey was conducted in Dec. 2008, approximately mid-season. The EC_a data were interpolated onto a 10 metre grid by kriging using the Vesper software package with a block size of 50 metres, interpolation neighbourhood of 90-100 points and a local exponential variogram model (Figure 1(a)). For the purpose of investigating any correlation with the accumulative NDVI values from the MODIS imagery, the 10 m grid data were further aggregated, by averaging, into ‘pixels’ coinciding with the MODIS image pixels.

Elevation

A digital elevation model (DEM) was constructed from the vertical data (z-) component of the acquired dGPS data using Arc/Info topogrid (Environmental Systems Research Institute Inc, Sydney, Australia) set to 10m resolution (Figure 1(b)). Again, for the purpose of investigating any correlation with the accumulative NDVI values from the MODIS imagery, the data were further aggregated, by averaging, into ‘pixels’ coinciding with the MODIS image pixels.

Results and Discussion

Figure 2 depicts the pair-wise correlations between the accumulative NDVI values, the EM38 survey data and the local elevation using the MODIS cells as the common grid. Each correlation plot yields a significant correlation (p<0.001).

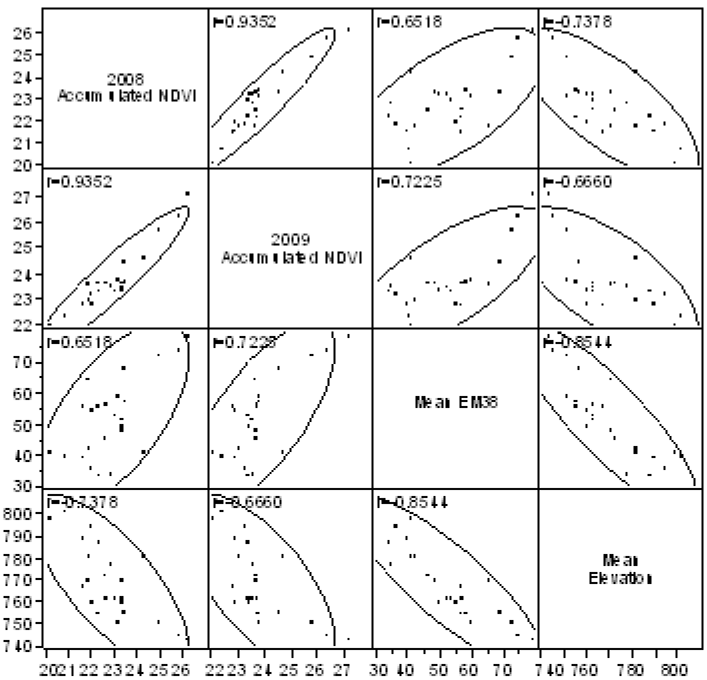


Figure 2. Correlation plots and Pearson correlation coefficients (r) between accumulated weekly MODIS NDVI for 2008 and 2009, apparent soil electrical conductivity (mS m^{-1}) and elevation (m), (n= 25), p-values for all correlations <0.001.

In this study site, and at the coarse spatial resolution of 250m (MODIS pixels), there is a strong correlation between elevation, EM-38 and net pasture productivity as indicated by accumulated pasture NDVI. In situations of low soil salinity, soil EC_a is highly correlated with soil moisture and flow accumulation (Guretzky *et al*. 2003, Hossain et al. 2010) and the strong negative correlation between EC_a and elevation in this site supports the notion that the lower slopes and valley floors are associated with higher water storage potential (heavier and or deeper soils) and greater water harvesting capability (flow accumulation) (Moore *et al.* 1991). Given the significant correlations observed between the accumulated NDVI, elevation and EC_a data at the lower, ~250m, spatial resolution, the obvious question is whether the original higher resolution EC_a and elevation data can be used as an indicator of the within-pixel variability of the accumulated NDVI data itself. If so, then this high resolution data could be used either as the basis of 'selecting' MODIS pixels for their reliability in representing whole-field biomass production estimates, or may allow sub-MODIS pixel refinements to pasture production estimates. For example, the original higher resolution EC_a maps (10 m) could be used to refine net pasture productivity maps by delineating within-pixel variability in factors such as available water or potential stability in water-holding capacity over time. At the very least, knowledge of within paddock hydrology derived from the higher resolution EM38/elevation data could add interpretative value the ~250m-resolution net pasture productivity data, for example were it to be used to inform variable-rate fertiliser or seeding (including composition) activities.

Conclusion

Significant correlations observed between net pasture productivity and elevation and EC_a at coarse scale suggests higher resolution soil maps such as that derived from EM38-type instruments may add significant interpretative value to low-resolution, remote pasture assessment tools like Pastures from Space by indicating sub-pixel zones of potential soil moisture stability, or at least indicate potential within-pixel variability in soil condition. Farmers often have limited funds to invest on-farm and these technologies have the potential to select the best responding areas in the best responding paddocks for pasture sowing, fertiliser application or soil amelioration. Within these selected areas variable rate applications of seed, fertiliser or soil ameliorant can be applied to further maximise return on investment. In the future variable pasture seed applications may even extend to species and variety changes to further improve returns (Hackney 2008). In addition, the technology highlights the need for differential grazing management between and within paddocks to improve pasture utilisation.

Acknowledgements

Part of this work was conducted within the CRC for Spatial Information (CRCSI), established and supported under the Australian Governments Cooperative Research Centres Program. The authors gratefully acknowledge Department of Land Information Western Australia (LandGate) for assisting with the provision of weekly MODIS satellite. We also thank Derek Schneider for his skilled technical assistance in the collection of field information and lastly the landholders for their understanding, cooperation and assistance. We acknowledge and welcome the reviewer's comments on the impact of this research on farm activities.

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