Geoderma Regional 6 (2015) 7–21

Contents lists available at ScienceDirect

Geoderma Regional

journal homepage: www.elsevier.com/locate/geodrs

Digital soil assessment of agricultural suitability, versatility and capital in Tasmania, Australia

Darren Kidd [a,b,*], Mathew Webb [a,b], Brendan Malone [b], Budiman Minasny [b], Alex McBratney [b]

[a] Sustainable Landscapes Branch, Department of Primary Industries Parks Water and Environment Tasmania, 171 Westbury Road, Prospect, TAS 7250, Australia
[b] Faculty of Agriculture and Environment, University of Sydney, 1 Central Avenue, Australian Technology Park, Eveleigh, NSW 2015, Australia

ARTICLE INFO

Article history:
Received 2 July 2015
Received in revised form 10 August 2015
Accepted 11 August 2015
Available online 14 August 2015

Keywords:
Digital soil assessment
Land suitability
Gross Margins
Biophysical Modelling
Nitisols, Acrisols
Solonetz
Lixisols, Podzols
Histosols

ABSTRACT

Digital soil assessment (DSA) is the application of interpretations to digital soil mapping (DSM). Since 2010, an operational DSA program has been underway in Tasmania, Australia, primarily for the assessment of agricultural land suitability for 20 different crops in newly commissioned irrigation schemes. This involves development of functional soil attribute and climate grids, initially undertaken in two pilot areas totalling 70,000 ha, with comprehensive soil sampling and temperature sensor networks. Through the Tasmanian State Government 'Water for Profit Program', this pilot land resource assessment has become operational and applied to the entire State (68,401 km^2), covering a total of 19 irrigation schemes. Using a combination of newly collected and legacy soil data and a suite of spatial explanatory covariates, a total of 218 80 m resolution 3D soil attribute grids were produced using the digital mapping approach, together with quantified prediction uncertainties. These grids have contributed to the 'Soil and Landscape Grid of Australia' and the 'GlobalSoilMap' projects. Using a similar approach, functional climate grids were generated for chill-hours, growing degree-days and frost risk. The digital soil and climate grids were applied to pre-defined enterprise suitability rulesets to produce 20 different maps of enterprise suitability, including opium poppies, and a range of perennial horticultural, cereal and vegetable crops, uploaded to a publically accessible spatial internet portal (Land Information Services Tasmania; LISTmap), which includes functionality to identify soil and climate limitations, as an indication of potential land management inputs. The suitability surfaces provide a regional indication of potential areas to expand or diversify into a range of cropping enterprises. However, some informative supplementary products were also developed to provide an overall spatial guide to the more versatile agricultural areas. This included an enterprise versatility index (by combining all suitability surfaces to identify areas more suited to more enterprises); and application of individual commodity 'financial gross-margins' to identify the highest-valued agricultural land in terms of earning potential. These products demonstrate the utility of functional soil property grids and the collective capacity of DSA to answer questions of agricultural potential; this can ensure the appropriate land is targeted for appropriate uses to stimulate agricultural markets and maintain food security.

1. Introduction

There is significant published literature and evidence demonstrating the proficiency of digital soil mapping (DSM) to provide functional soil property and class maps for a range of depths, across different soil and landscape types, and at different resolutions, depending upon need (Lagacherie, 2008; Lagacherie et al., 2007). DSM involves a variety of different disciplines, including the development of predictive spatial modelling functions of soil properties or classes using point-source calibration sites, along with spatial explanatory variables to map the spatial variation between sites. Popular DSM approaches employ environmental correlation (*scorpan*) utilising intensive computing capabilities and geostatistics to produce quantitative 3-dimensional grids of soil properties or classes, with the advantage of providing quantitative estimates of associated uncertainty (McBratney et al., 2003). DSM has perceived advantages over traditional polygonal soil mapping in that the process is quantitative, repeatable, objective, can be applied over large areas of sparse information, and routinely updated as new data is collected (Carré et al., 2007; Minasny et al., 2008). The raster outputs are better able to simulate the continuous and gradational variations of spatial soil properties, across multiple depths (MacMillan, 2008; McBratney et al., 2003). In recent years, this science has become increasingly operationalised, with GlobalSoilMap (Arrouays et al., 2014) being a globally significant example. DSM products, now largely accepted by mainstream soil science (Carré et al., 2007), are progressively being used for a variety of purposes to answer soil productivity and environmental assessments across a range of scales; locally,

* Corresponding author at: Sustainable Landscapes Branch, Department of Primary Industries Parks Water and Environment Tasmania, 171 Westbury Road, Prospect, Tasmania 7250, Australia.
E-mail address: Darren.Kidd@dpipwe.tas.gov.au (D. Kidd).

http://dx.doi.org/10.1016/j.geodrs.2015.08.005
2352-0094/

regionally and globally (Hartemink, 2015), including environmental processes and agricultural suitability (Harms et al., 2015). This is achieved through applying interpretations to functional DSM grids, and integrating with appropriate biophysical data such as vegetation, climate and terrain for quantitative decision making and support (McBratney et al., 2012); this process is referred to as digital soil assessment (DSA) (Carré et al., 2007). Finke (2012) surmised that DSM has reached an acceptable level of scientific maturity for the focus to now shift to DSA, and further into soil security and quality (McBratney et al., 2012, 2014).

The aims of this paper are to present a regional DSA for the whole of Tasmania for enterprise suitability assessment, and development of some preliminary spatial products to inform agricultural versatility and capital. The structure is as follows: first, we briefly review the operational DSA undertaken in the two pilot areas; describe how the pilot DSA approach was expanded using the soil and climate data collected in the pilot phase, and integrated with legacy soil data to generate state wide DSM surfaces to inform an Enterprise Suitability Assessment (ESA) for the whole State of Tasmania, for 20 different enterprises; describe, present and discuss preliminary state-wide maps produced for agricultural versatility and spatial gross-margins estimates; and examine the pros and cons of the suitability framework, and how this could be improved with a future sampling campaign.

1.1. Operational DSA

DSA was proposed by Carré et al. (2007) for assessing threats to soil (resulting in land degradation) and functions of soil, such as biophysical interactions, production and biodiversity, where DSM is a precursor to DSA. Therefore, DSA can be used to for identifying environmental risks and for land evaluation, such as agricultural land suitability for various crops, and integrated with other environmental or socio-economic data for tailored end-user requirements (Carré et al., 2007).

Examples of DSA, in an operational context, are demonstrating the functionality of DSM and producing credible and effective products when integrated into DSA. Van Zijl et al. (2014) evaluated a DSA approach for rapid land suitability assessment in the Namarroi area of Mozambique. A SoLIM (Soil Land Inference Model) approach (Zhu et al., 1997), integrating conceptual soil mapping units with pedometric inference techniques (Zhu et al., 1997) produced predictions of soil production potential, erosion risk, and compaction risk from a range of expert-based rulesets. The authors were able to demonstrate the relatively rapid production of functional soil property mapping to determine spatial land suitability from few field observations, with an absolute validation sample accuracy of 80%, and over 59% (with 95% confidence limits).

Thomas et al. (2015) and Harms et al. (2015) describe an application of operational DSA for agricultural land suitability assessment in Northern Queensland, primarily to explore opportunities for irrigated agriculture in an area of 155,000 km^2 in the Flinders and Gilbert catchment. The project used a combination of legacy and newly collected soils data, along with a suite of *scorpan* (McBratney et al., 2003) spatial covariates to predict of range of different soil properties using a robust regression tree (RT) approach (Breiman et al., 1984; Grunwald, 2009; McKenzie and Ryan, 1999; Moran and Bui, 2002). The validation diagnostics of DSM-derived functional soil property maps produced for this DSA were considered appropriate for the requirements of the regional-scaled suitability assessment, and were applied as input parameters to a range of land suitability rulesets to identify areas that were suitable for irrigated agricultural expansion. This operational DSA followed a similar exercise in Tasmania, Australia, producing land suitability maps for 20 different crops to inform irrigated agricultural expansion.

1.2. Tasmanian DSA

Tasmania is undergoing a period of agricultural expansion and investment in irrigation. As at June 2015, 19 irrigation schemes have been commissioned in addition to existing irrigation areas, funded by a combination of Federal, State and private investment; of these, 11 are now operational, 2 under-construction, and the remainder at the planning stage (Tasmanian Irrigation, 2015).

In 2010, the Tasmanian Department of Primary Industries Parks Water and Environment (DPIPWE), in collaboration with the University of Sydney Faculty of Agriculture and Environment and the Tasmanian Institute of Agriculture (TIA) launched the 'Wealth from Water' project (DPIPWE, 2015d), developing a land suitability framework based around operational DSM to stimulate investment and development of the irrigation schemes. The project covered two separate areas, totalling 70,000 ha (Kidd et al., 2014b). This was a 'proof of concept' pilot exercise which applied DSM for the generation of a suite of functional soil property and climate gridded surfaces to pre-defined 'enterprise suitability rule-sets' (developed by TIA) for 20 different enterprises, to inform an 'enterprise suitability assessment' (ESA) at 30 m resolution. The ESA was effectively a land suitability approach (FAO, 1976) of land evaluation, limited by the least suitable soil or climate parameter (Klingebiel and Montgomery, 1961). The TIA-derived rulesets all contain soil, terrain and climate parameters that were identified by industry workshops, available literature and agronomy experts to be the major limitations to each crop; many of these limitations can be effectively managed by various technologies, however, they would require either capital or ongoing investment, which will determine profitability. This inferred management underpins the ESA.

The term 'enterprise' was chosen over more commonly applied land use type (or land utilisation type) (FAO, 1976) due to the level of management inferred for each crop, identified by the parameter ranges of each rule-set. The basis the suitability framework provides a query-enabled list of limiting factors through DSM, identified to guide the management practices that could help overcome the limitations. In addition, market tools, financial modules, irrigation case studies and fact sheets were also developed (DPIPWE, 2015c, 2015d), which all infer that each land utilisation type should be considered in conjunction with the underpinning management requirements to manage limitations for an enterprise to become successful (profitable). The limitations requiring management were identified through the series of fact sheets; in addition, a 'default' or typical management was developed by industry and TIA for the purposes of identifying the suitability assessment parameters, and to provide the basis of the cropping gross-margins analysis. Finally, the term 'enterprise' was applied by the Tasmanian Government to the programme to identify each land use type as a business consideration, and is used throughout this paper to maintain consistency.

931 soil cores were sampled, including an independent validation set (30%) (Kidd et al., 2015a). The observations were modelled as a function of spatial covariates using Regression Tree (RT) combined with kriging of the model residuals where spatial-autocorrelation was sufficiently strong; that is, regression-kriging (RK) (Hengl et al., 2004, 2007; Odeh et al., 1995). The DSM methodology and results are presented and described in more detail in Kidd et al. (2012, 2014a, 2014b, 2015a). 271 temperature sensors were installed in optimum locations to ensure representation of the full terrain covariate distribution, and climate grids generated from this data using the terrain covariates, as described in Webb et al. (2015). The soil and climate grids, and resultant ESA maps from interpreting the outputs of the enterprise suitability rule-sets, were uploaded to a publically accessible spatial web-based portal (DPIPWE, 2015e), where growers or potential investors could view the ESA maps, and query any part of each map to determine what any limiting soil or climate factors might be.

Gross-margins economic data for each enterprise was also developed by DPIPWE into a set of Gross Margins Analysis Tools (GMAT) to