

WHAT DIFFERENCE DOES DETAILED SOIL MAPPING INFORMATION MAKE? A CANTERBURY CASE STUDY

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Abstract

This study is based on a 120 hectare farm on the Canterbury Plains. We compare different scale soil maps and soil data from the Fundamental Soils Layer (FSL – <http://iris.scinfo.org.nz/layer/137-fsl-south-island-all-attributes/>), S-map (<http://smap.landcareresearch.co.nz/>), a detailed farm-scale soil series map, and S-map sibling data associated with a survey of 723 auger holes across the farm. Auger holes were on an approximate grid with 40-metre separation (approximately seven auger holes/hectare). For comparative purposes the soil series identified in the FSLs and farm-scale soil maps have been recorded in the S-map database as siblings. At the different map scales the study area is represented by four soil siblings in the FSL, 12 soil siblings in S-map (seven dominant and five subdominant soil siblings across the map units), nine soil siblings in the farm-scale map, and over 200 different soil siblings in the auger dataset. Different interpolations of soil properties were also generated, each using different subsamples of the auger dataset, to visualise variation in representation of soils with different auger sampling densities.

The auger points give an idea of the variability in texture, horizon thickness, and depth to stones within a single S-map sibling, as well as within soil map units from different scales. The impact of this spatial variability on estimates of profile available water, drainage and nutrient losses from each soil map unit, farm block and whole farm is determined and graphed. We also discuss the different costs of soil sampling and mapping at each scale, along with some general recommendations.

Introduction

The need for farm-scale mapping to support regional council (RC) plans and policies arising from implementation of National Policy Statement for Freshwater Management has been identified in a number of previous FLRC papers (Manderson & Palmer 2015; Fraser et. al. 2014). Currently S-map is being funded by a consortium of central government and regional councils. The amount of farm-scale soil mapping has increased in recent years, and is expected to increase markedly as RC policies are implemented. However, the cost of farm-scale mapping is significant, depending on the level of detail required (Carrick et al. 2014),

and there are few studies that compare the impact of using soil information at different levels of detail (mapping scales).

The objective of this paper is to compare in a highly variable soil landscape the impact of mapping at different scales on characterisation of soil water storage and nutrient leaching.

Soils Data

In order to test the assertion that increasingly detailed soil mapping can make an improvement to modelling of farm nitrate leaching, we selected an area with a range of different quality soil data (Table 1). The area was selected to encompass a high level of spatial variability across multiple soil attributes. The site we selected was a 120 hectare farm on the Canterbury Plains with high variability in

- 1) soil depth (depth to very stony layer with >35% stones)
- 2) texture (proportion of sand, silt loam, and clay)
- 3) natural drainage class (well, imperfectly, and poorly drained).

Table 1: The map scale and approximate cost of datasets used in this study.

Map type	Scale	Approximate cost
FSL	1: 126 720	Available Free
S-map	1: 50 000	Available Free
Farm map	1: 10 000	\$35/ha* = \$4.2k
Paddock grid	40 m grid survey (approximately 1:5000 scale)*	10 mins/auger, with labour of \$100/hr = \$12k + mapping \$3k

* Manderson & Palmer (2006).

The fundamental soil layer (FSL - <https://iris.scinfo.org.nz/layer/137-fsl-south-island-all-attributes/>) dataset is based on New Zealand Land Resource Inventory (NZLRI - <https://iris.scinfo.org.nz/layer/135-nzlri-south-island-edition-2-all-attributes/>) polygons that were recompiled at 1:63 360 (inch to mile) and used the best available soils data. In the case of this part of the Canterbury Plains, this was based on the original Plains and Downs Survey (Kear et al. 1967), although other local surveys may have been consulted (e.g. Cox 1978). The Plains and Downs soil survey was mapped at 1:126 720, but NZLRI mappers recompiled the soils boundaries onto newer aerial photos and 1:63 360 scale topographic maps that had become available since the completion of the original survey. Subsequently the FSLs were created by merging knowledge of soil profiles and soil properties from the National Soils Database (NSD) and any additional published and unpublished soils information into a single integrated dataset containing a soil classification, and 17 soil attributes (Barringer et al. 1998).

S-map is the new spatial database for New Zealand soils (<https://smap.landcareresearch.co.nz/>) and has been under development since 2003 (Lilburne et al. 2004, 2012). Like the FSLs, S-map incorporates historical survey data from soil survey reports and files, but fills gaps with new data and provides more quantitative data for a range of soil physical characteristics for each soil individual occurring within a map unit. In the

case of this survey area, the S-map polygons are based on estimation of soil boundaries from aerial photography, the adjacent soil map by Cox (1976), the previous Plains and Downs soil survey (Kear et al. 1967), and the soil surveyor's understanding of the soil types and soil pattern from mapping in the surrounding landscape. Although the farm-scale map was not directly used in the development of the S-map polygons for this area, this previous mapping experience, together with a number of other farm maps completed over time in this area, would have collectively influenced the S-map soil surveyor's understanding of soil-landscape relationships in this area. Although generally at 1:50 000 scale, S-map is structured to incorporate spatial information across a range levels of precision and accuracy. The database records the surveyor's assessment of the level of confidence associated with both the values recorded for each soil attribute and the accuracy of map unit components. The database has been designed to provide quantitative soil information for modellers and to provide the best available soil data (whether measured, estimated or interpreted) for use by land managers and policy analysts.

The farm-scale map was compiled over a period of time (Trevor Webb, pers. comm.). An early 1940s soil map, from when the property was a sheep stud farm, was improved in the 1980s based on a line transect survey, set out as a grid with observations at 40-m spacings. In the north block the surveyor logged soil characteristics, including texture, stone content and soil mottling (wetness/drainage), at 20-cm depth intervals to 60-cm depth, as well as depth to gravels or sand (where they were reached). The soil legend from Cox (1978) was used, data for profiles were plotted on paper and colour coded by different soil type, and soil type boundaries were drafted by eye. The south block was mapped at a later date to the north block, with the soils observed to 100-cm depth and morphology recorded to the nearest 10-cm depth. Soil type boundaries were drawn up in the same manner as the north block. The farm-scale map is approximately 1:10 000 scale.

The original surveyor assisted this project by matching the soil types on the three soil maps and the auger point descriptions with siblings in the S-map database. Additional S-map siblings were created as necessary. This involved using the survey observations to define the profile classification and functional horizons of each unique soil type, along with estimates of the range of profile depth, horizon thickness, clay, sand and stone content. To obtain quantitative estimates of sand and clay content, the original surveyor matched particle size laboratory data from 146 unique horizons from similar soils, either on-farm or nearby, with the observed field texture class.

Each sibling was entered into the S-map database to facilitate access to the pedo-transfer functions built into the S-map inference engine (Lilburne et al. 2014). Estimates of profile available water (PAW) and the OVERSEER® input parameters were generated for each unique sibling identified on the three maps and the auger point observations.

Modelling of estimated nitrate leaching

An intensive farm system with centre pivot irrigation where dairy cows are grazed over winter was defined in the OVERSEER® Nutrients Budgets model. It was assumed that the pivot irrigator had not been enabled for variable rate irrigation, so the farm was irrigated according to a fixed, relatively conservative schedule of 10 mm every five days from October to March.

Each of the set of 239 unique siblings that represent the soil types in the three maps and the auger points was run through the OVERSEER® farm system. Modelled estimates of nitrogen

lost to water from each sibling were recorded and linked to the spatial soil polygon and auger point data.

Results and Discussion

Comparison of different soil maps

The three soil maps and auger survey data used in this analysis are shown in Figure 1. As expected, the overall pattern of soil distribution is similar in all maps but the boundary definition improves and the minimum unit size decreases as the scale of the maps becomes finer. Differences between datasets in both the number of map units and soil siblings are summarised in Table 2. The farm-scale map is somewhat simplified compared with the auger survey from which it was made, indicating some variability of auger records has been lost in drawing a polygon-based map. The 1:50 000 scale S-map, also shows less spatial detail in map units (8 versus 26 map units in the farm-scale map), but some of this soil variability is encompassed in the greater number of siblings represented in map units (e.g. a number of S-map units contain three siblings, compared to a maximum of two siblings in the farm map). Thus, the total number of siblings is similar between S-map and the farm-scale maps, but there are a number of differences in the specific siblings that occur in each map. For example, the farm map has siblings mapped from the Balla family, which is dominated by clay texture, compared to the dominantly silty-textured Wakanui family that was mapped in these areas in the S-map and FSL versions. The area of siblings from the sandy-textured Barrhill family is more extensive in the farm map, whilst S-map has larger areas mapped as siblings from the silty-textured Templeton family. The FSL map has the most simple map unit representation, and shows only dominant soils for each map unit, so contrasts quite strongly with the other datasets in terms of the number of map units and number of siblings (Table 2).

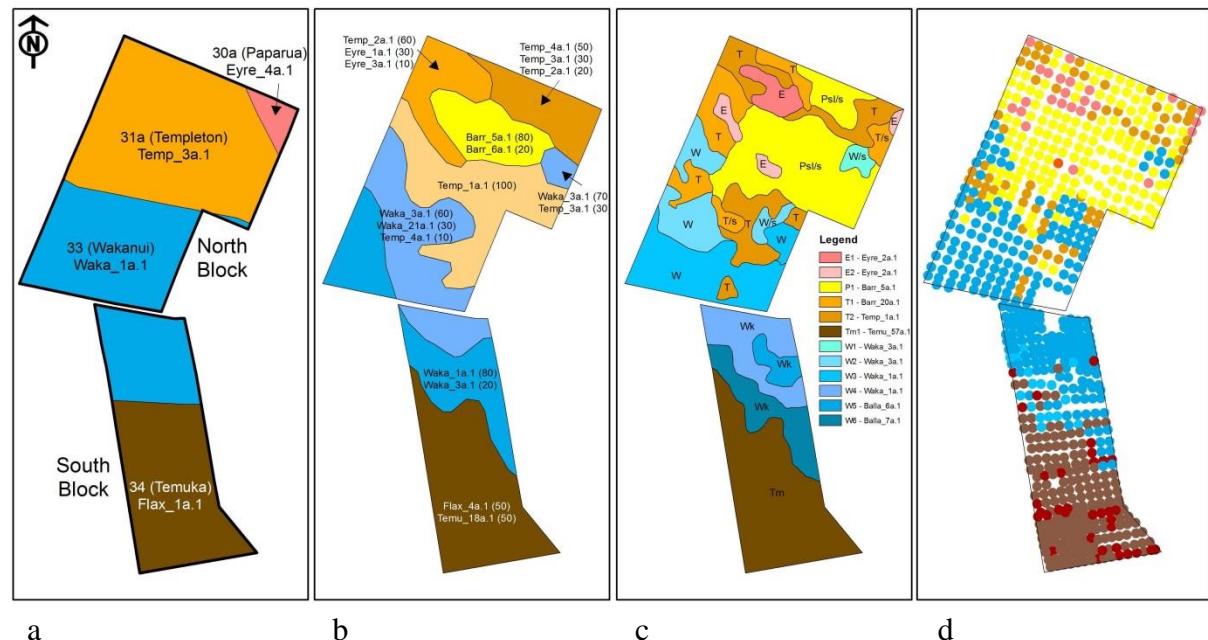


Figure 1: Soil maps used in this study: a) fundamental soil layer (FSL), b) S-map, c) farm-scale map, d) auger survey.

Table 2: Summary of the scale and thematic resolution differences between the four soils datasets illustrated in Figure 1.

	FSL	S-map	Farm map	Auger survey
Scale	1: 126720	1:50 000	1:10 000	1:10 000+
Polygons	4	8	26	723 augers
S-map Families	4	6	6	8
S-map Siblings	4	15	13	207

Another source of variability is the spatial variation in soil properties, even within the same soil type. The three soil maps follow the traditional approach, whereby a modal or average value is assigned to each soil type, for example, a topsoil clay content of 25%. In this study, we were able to explore the actual variability, as measured by the individual auger points. An example of the variation within a single sibling, Eyre_2a, is shown in Figure 2. The depth to very gravelly horizons varies from 23 to 40 cm, and the clay content of the upper subsoil horizon, immediately below the topsoil, varies from 13% to 19%. Figure 3 shows the higher level of variation found within the Waka_42a sibling in terms of the thickness and clay content. For example, the third clayey-textured horizon, which will dominate water movement in the soil, varies in depth from surface from 40 to 70 cm and thickness from 10 to 50 cm.

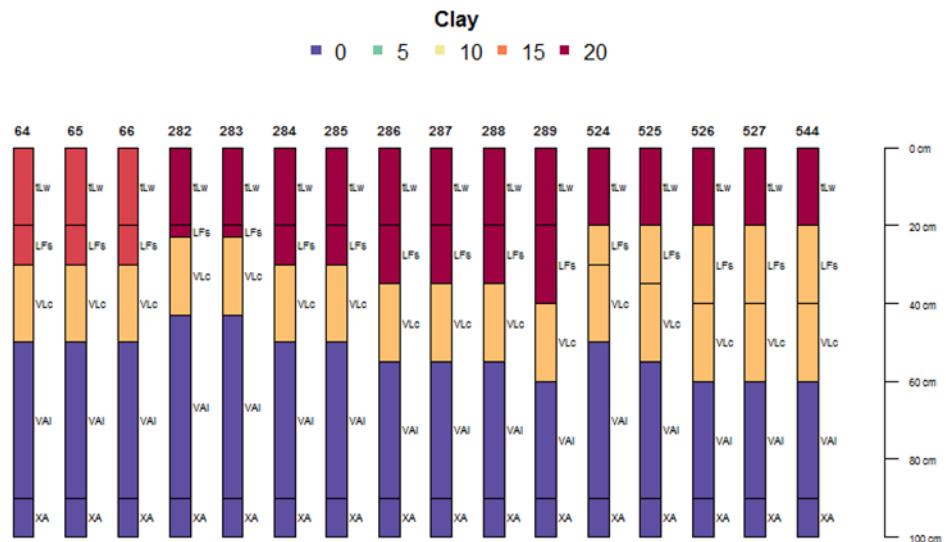


Figure 2: Variability in percent clay in the functional horizons of the soil profiles of auger records assigned to a single S-map soil sibling (Eyre_2a).

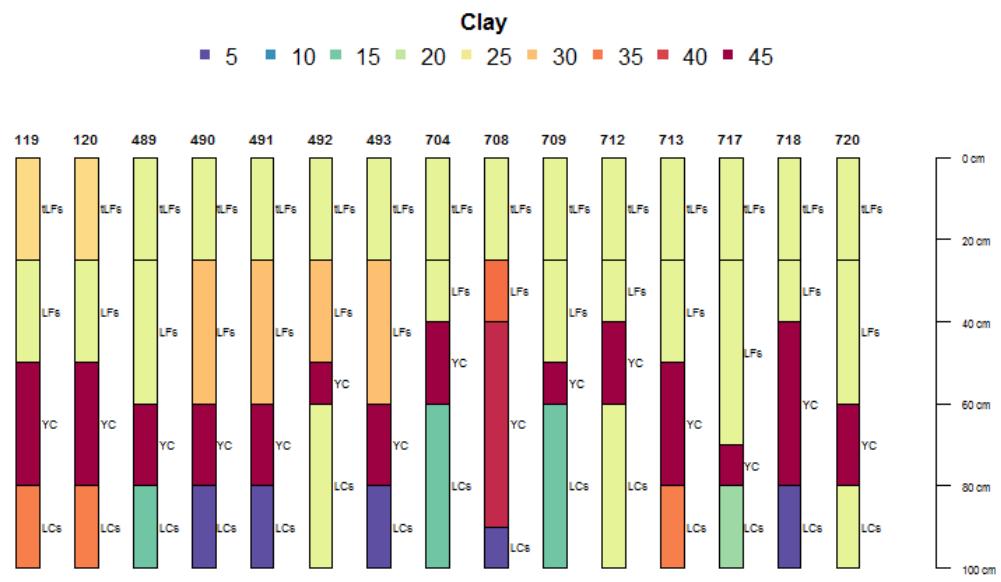


Figure 3: Variability in percent clay content in the functional horizons of the soil profiles of auger records assigned to the same S-map soil sibling (Waka_42a).

Comparison of variation in soil water holding capacity

The variation in the spatial distribution of profile available water (PAW) for the three soil maps and auger survey data are shown in Figure 4. As expected from the soil class maps (Figure 1), the overall pattern of PAW is similar in all maps; for example, there is a consistent general pattern of clayey texture soils in the south block showing higher PAW than the loamy soils in the north block. However, with increasing map detail there is an evident improvement in the boundary definition and spatial extent of different areas of PAW. Table 3 summarises the impact of the different levels of mapping detail on the overall farm and individual block average PAW. It would be generally assumed that with increased mapping detail we would expect a more accurate estimate of PAW. At the farm level, only the FSL map shows a substantial difference with the auger points, with both the farm map and S-map showing a close match to the auger map. However, at the block level, S-map and the farm map do show differences, with up to a 20-mm difference in the S-map estimate of PAW for the south block, when compared to the auger map.

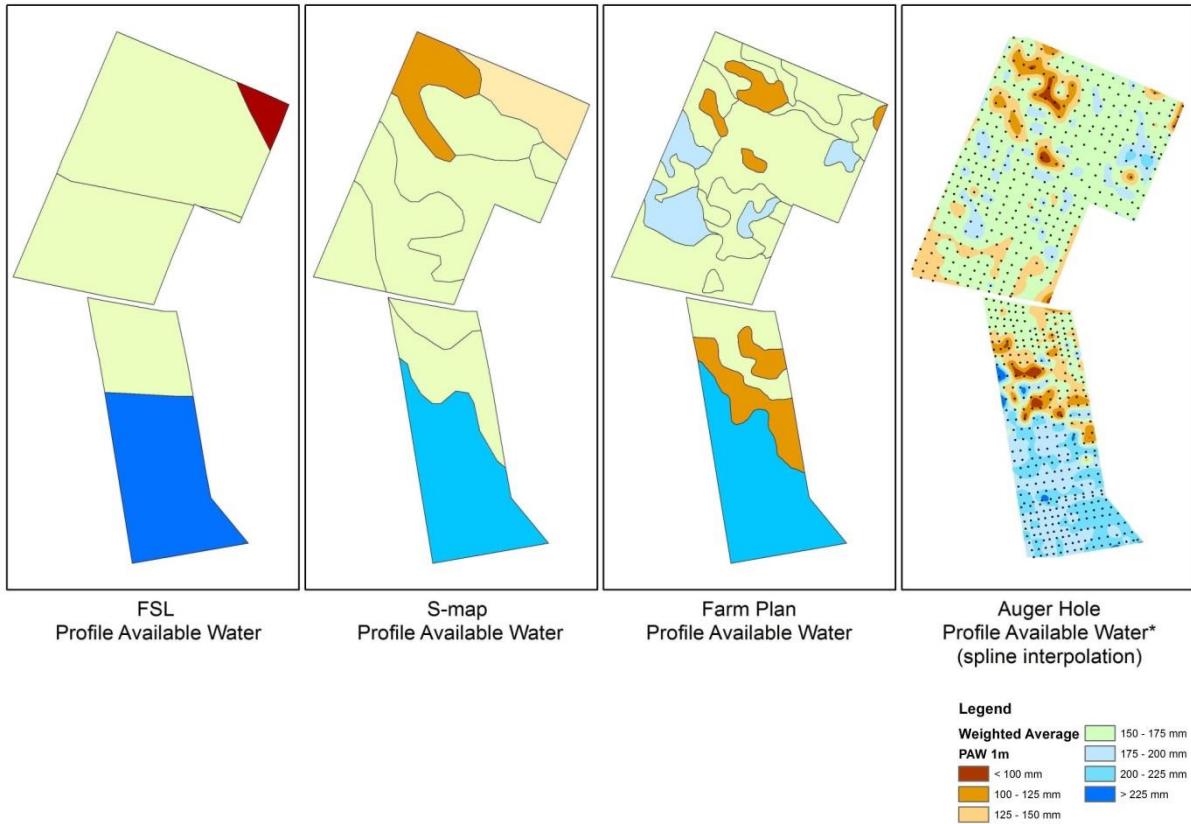


Figure 4: Profile available water (PAW) derived from the four soils datasets used for this analysis. In the three soil maps, PAW is the area-weighted average of the multiple siblings that may occur within a map unit, whereas the auger map is derived from an interpolation of the point estimates of PAW.

Table 3: Average PAW across the whole farm and between the north and south blocks.

	FSL PAW	S-Map PAW	Farm map PAW	Auger PAW
Whole farm	143	171	164	168
North Block	136	156	162	158
South Block	157	199	169	179

One challenge in soil survey is to determine the appropriate number of observations required to achieve a reliable representation of the soil spatial distribution, and to balance the number of observations with the cost. Figure 5 illustrates the changes in the map of PAW derived from auger points as the number of observations is reduced from 723 auger points (6 observations/ha) to 55 auger points (0.46 observations/ha). The spatial resolution of individual areas of PAW clearly becomes more coarse, but at the overall farm and block level the estimate of PAW does not substantially change as the observation density decreases (Table 4). Based on the cost estimates in Table 1, for this particular farm with high apparent soil variability, the cost of the auger survey could be reduced from approximately \$12,000 to \$1,000, to produce a similar estimate of farm or block average PAW.

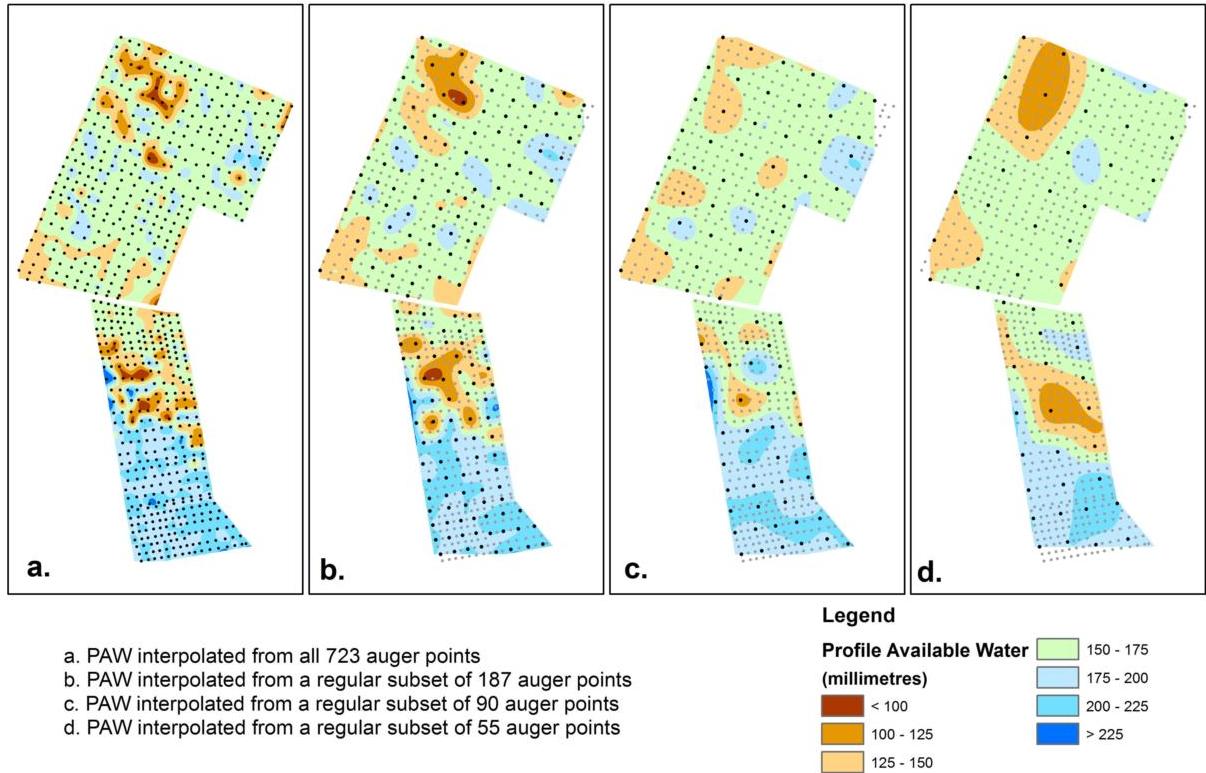


Figure 5: The effect on auger record-based estimates of PAW (mm) of reducing the sample density of the auger observations: a) interpolated PAW using all 723 auger observations, b) interpolated PAW from every second observation (187 obs.), c) interpolated PAW from every third observation (90 obs.), d) interpolated PAW from every fourth observation (55 obs.). The observations used are the larger black points, unused observations are smaller grey points.

Table 4: Variability in PAW (mm) across the whole farm and between the north and south blocks depending upon the number of auger observations used to estimate PAW. Subsamples are by regular selection of every 2nd, every 3rd and every 4th observation from the original sample.

	All obs.	2 nd obs.	3 rd obs.	4 th obs.
Whole farm	165	165	168	162
North Block	159	159	161	157
South Block	176	175	181	170

Comparison of variation in predicted N leaching

The relative impact of the differences between the soil maps on the OVERSEER model predictions of nitrogen leaching (N-loss) are shown in Figure 5. Within the farm, the spatial variation in predicted N-loss from the auger points varies from 1 to 66 kg N/ha/yr, with the three soil maps showing an apparent difference with the reference auger-based map, mostly in the north block. Both S-map and the farm-scale map show a similar pattern of variability. Table 5 summarises the impact of the different levels of mapping detail on the overall farm and individual block estimates of N-loss. Overall, S-map and the farm-scale map show similar results, with the largest mean farm difference of 5 kg N-loss/ha/yr between the FSL map and the reference auger-based map.

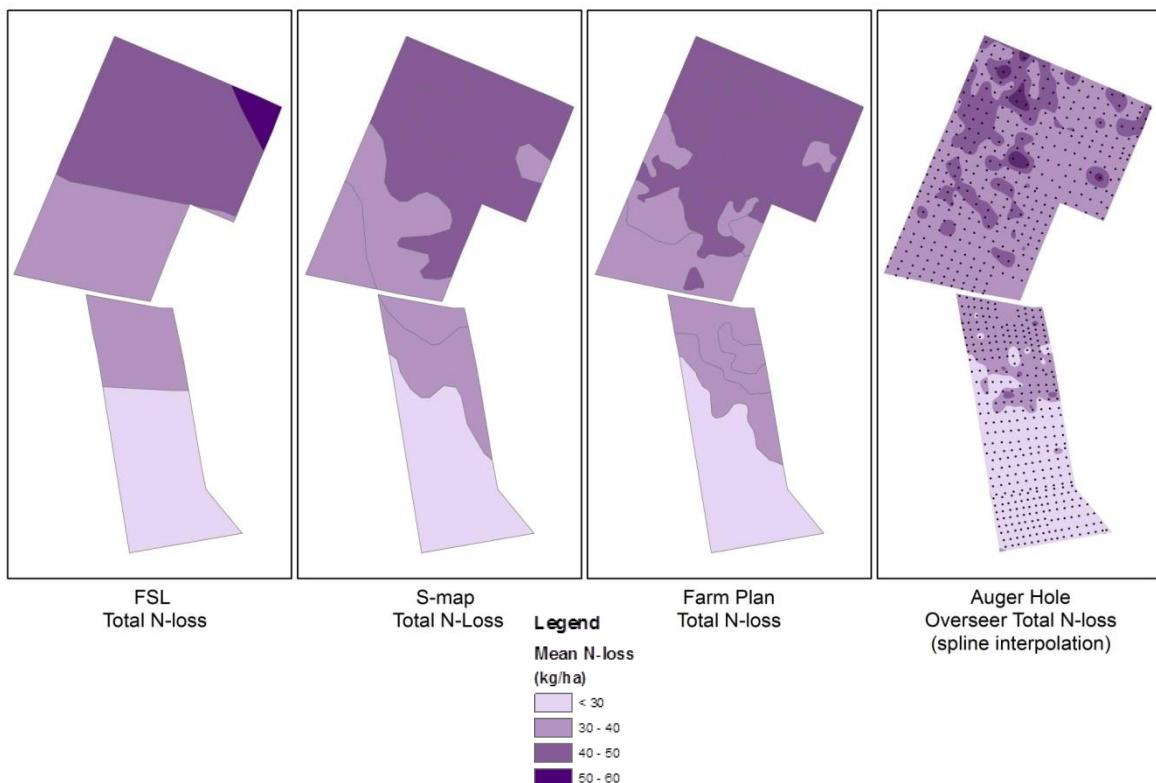


Figure 5: Total N-loss (kg/ha) for fixed irrigation simulations in OVERSEER using the FSL, S-map, farm map and auger observation datasets.

Table 5: Total N-loss (kg/ha) for fixed irrigation simulations in OVERSEER using the FSL, S-map, farm-plan and auger observation datasets. The figures in brackets represent the total N-loss (kg) over the entire block.

	FSL	S-map	Farm map	Auger survey
Whole farm	36.9 (4408)	34.7 (4145)	33.8 (4037)	31.9 (3810)
North Block	40.7 (3134)	39.4 (3034)	39.1 (3011)	38.8 (2988)
South Block	30.1 (1277)	26.1 (1108)	24.1 (1023)	24.3 (1031)

We note that just as using OVERSEER® to analyse different farm system mitigation scenarios has some procedural pitfalls (Howarth & Journeaux 2016), so too does using OVERSEER® to explore the effect of soil variability. For example, it is not appropriate to

simply change the soil inputs without also considering how this will impact on the irrigation settings and, consequently, whether levels of pasture or crop production need to be changed to reflect the suboptimal irrigation.

In this case study, we have not considered the impact of uncertainty in the pedo-transfer functions that are used to estimate attributes such as PAW. In future work, we plan to combine soil variability and scale with pedo-transfer function error to obtain estimates of the uncertainty in estimates of PAW and nitrogen leaching

Conclusions

From our analysis we can draw the following conclusions:

- Whilst it is commonly acknowledged that soils can be highly variable over quite small distances, such as soil patterns in alluvial landscapes, it is important to determine the key soil attributes that may substantially impact a land management issue, and whether these are likely to be significantly different across sufficient area to warrant detailed farm-scale mapping. For example, in our study farm, while the soils are highly variable, the area is dominated by deep soils, meaning the more detailed soil mapping didn't necessarily result in a substantial change in the key soil attribute of PAW, that underpins predictions of N-leaching.
- With sufficient dollars it is possible to map soil variability in great detail, but there may be little benefit if a) there is not much variation in key properties like water holding capacity, or b) the level of detail is beyond what can be practically managed. For example, a variable rate irrigator can take advantage of a high level of spatial detail in PAW whether this is obtained from field sampling or sensing (e.g. E-M mapping). However, if the farm management options for minimising nitrogen losses lie in managing stock numbers, the high level of spatial detail may not be of any use as it is impracticable to fence the many hotspots (e.g. as in the north block in this case study).
- S-map may be good enough at this site based on the 80:20 rule: 80% of the soil variability and effects of that variability are explained for 20% of the effort. The remaining 20% of variation and its effects might take another 80% of effort, especially given the expense of collecting the detailed, high density auger observations or proximally sensed information.
- If the 80:20 rule does apply, then key differences to identify (with respect to water storage and nutrient management) are texture, stone content, depth of horizons, and drainage class. The importance of these properties for nitrogen losses as estimated by OVERSEER was identified by Pollacco et al. (2014). Looking at the multiple siblings within a polygon in S-map may help identify where there is high variability that is worth mapping.

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