4 Site investigations

This project ('Understanding subsoil constraints in the HRZ') has been largely desktop and regional in scale, however four paddocks were visited as part of this study and surveyed. This work was done in order to create some engagement with four farming groups in the HRZ and to provide one example for each group of soil properties and variability at the paddock scale. An important requirement was that the sites actually fell within the bounds of the 500–900 mm mean annual rainfall (MAR) isohyets of the high rainfall zone. The sites chosen by the cropping groups were at Marrar in NSW (Farmlink), Yarrawonga (Riverine Plains Inc.) in Victoria, Willaura (Southern Farming Systems sub-branch, Lake Bolac) in Victoria and Frances in South Australia (MacKillop Group) (Figure 18).

Site investigations were carried out to determine the level of within paddock variability in subsoil physical and chemical conditions and implications of this for yield and amelioration strategies. A key assumption behind the rationale of the site investigations was that subsoil conditions impacted either directly or indirectly on the water use of the crop. A direct impact of subsoil constraint is the physical or toxic restriction of root growth, hence limiting the volume and range of plant available water (PAW) for growth or indirectly through waterlogging.

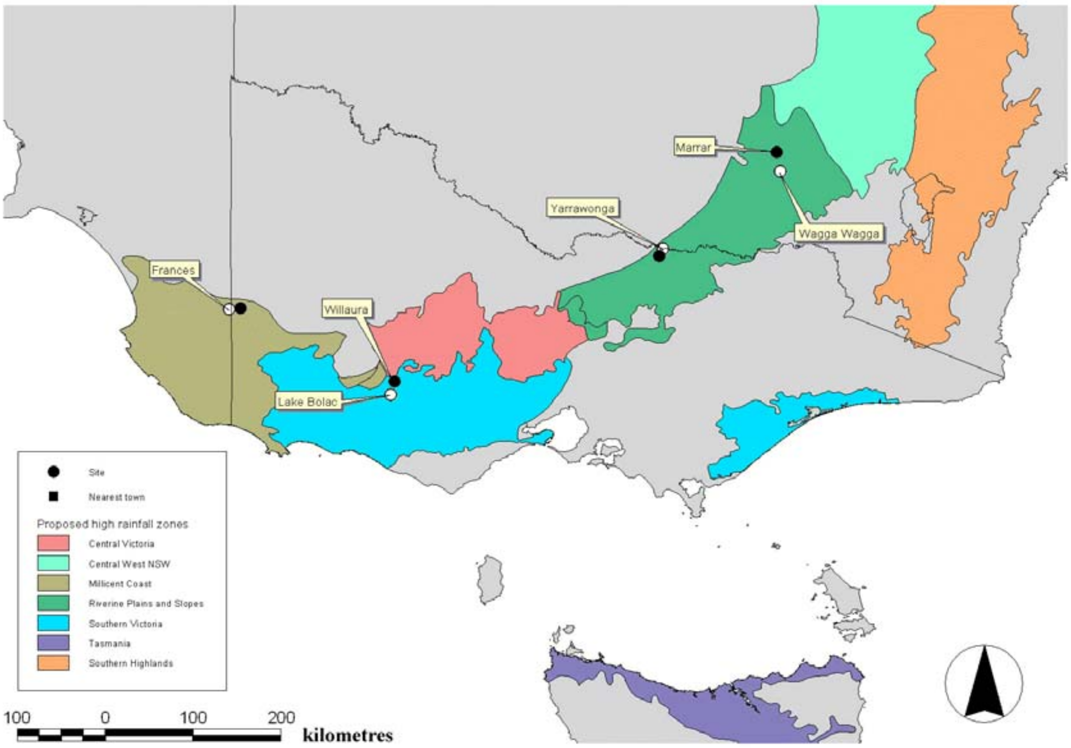

Figure 18. Map showing site locations relative to HRZ boundaries and zones.

4.1 A brief review of paddock survey methods to predict spatial distribution of subsoil constraints

Spatial variability of subsoil constraints

The use of precision farming techniques to identify subsoil constraints in the cropping industries has increased world wide in the last decade with the advent of differential global positioning systems (DGPS) and cost effective mobile sensor and logging systems. Under the principles of precision agriculture methods and the concept of variable rate management, there are potential savings for farmers in inputs applied to low productivity areas and gains from targeted or increased application of inputs to more productive areas within a paddock. However, in the HRZ use of spatial data to assess amelioration and drainage works is of greater issue than in non HRZ traditional low rainfall cropping areas. The purpose of the following section is to review aspects of previous work using spatial survey techniques in identifying subsoil constraints and assess these in relation to their applicability to conditions in the HRZ.

The nature of subsoil constraints in the HRZ affecting survey method

Subsoils in the HRZ have been described previously as typically either duplex or gradational with an underlying layer of medium to heavy clay that impedes drainage and hence causes perched water tables and waterlogging of the root-zone. In a particular sub-paddock area the amount of clay present in the subsoil, the thickness of any clay layers, the presence of associated landscape features and the sequence of landforms combine with interactions between the clay and the chemistry to influence the subsoil constraints. Processes occurring in the soil and interactions between land management and the environment can be far more pronounced in a high rainfall environment compared to those in more traditional cropping areas. High yield potential in the HRZ encourages larger applications of nitrogenous fertilisers, which increase the likelihood of environmental losses of N and soil acidification. Trafficking by machinery and/or previous grazing of pastures by stock ahead of cropping can cause compaction layers to develop in the soil when it is exposed to saturated conditions for long periods. Soil is more vulnerable to compaction from grazing dual-purpose cereals in the HRZ as soils are likely to be close to field capacity at optimal grazing time and there is less soil protection provided than in a conventional pasture.

Yield maps are readily available to farmers but their value in planning and management is limited by seasonal variability and lack of understanding of the causes of within-paddock variation. Ground level EM38 surveying has long been used in several applications such as mapping salinity, clay content and soil moisture. However the complex interactions of the soil properties influencing electromagnetic induction (EMI) readings can limit the opportunities for interpreting yield maps.

Techniques for identifying subsoil constraints in the HRZ

Direct assessment of subsoil constraints by field-based means alone such as pit surveys and high density grid sampling are costly and are best carried out in conjunction with other spatial information that allows the information to be extrapolated either locally or regionally depending in the type of constraint. Consequently, there is increasing popularity in the use of commercially available EMI instruments in conjunction with Differential Global Positioning Systems (DGPS). This review does not include the use of ground penetrating radar as it is not commercially available to farmers.

The most common tool for remote sensing of subsoil constraints is the EM38 (Geonics™) in either vertical or horizontal mode of both (Sudduth *et al.* 2001). Other electromagnetic (EM) instruments such as the EM31 provide indication of conductivity up to 3 m depth beyond the root zone of most annual crops. Gamma radiometric sensors can be used to map soil textural differences in the upper 0.3 m of the profile but these are less readily available. The principles underlying the technology have been well documented in the literature. The 3 principal types of sensor available are described below.

1. Electromagnetic Induction. The principle of EMI application in soil survey is that EM pulses are proportional to the electrical conductivity of the soil. Instruments such as the Geonics™ EM38 and EM31 measure the apparent conductivity (EC_a) resulting from the texture, moisture and salt content of the soil, as well as from other conductive material such as ferric gravel. A transmitting coil creates a magnetic field that induces a secondary field in the soil. These two magnetic fields are sensed by a receiving coil, and the ratio between them represents the soil conductivity. Connectivity of pores and moisture in the soil has a positive effect on the conductivity reading. The EM38 is used in horizontal and vertical modes to indicate conductivity for two depth ranges. EMI readings can be used to guide selection of sampling points across the surveyed conductivity range. Relationships between measured soil properties and EMI data can then be applied to map soil properties across the whole area.
2. Gamma Radiometric Spectroscopy (GRS). Survey of soil mineralogy using gamma radiometric spectroscopy (GRS). has been developed in the mining industry which has applied the technology extensively through airborne GRS survey for mineral exploration. The

phenomenon of radioactive decay provides unique spectral signatures for material close to the ground surface, dominantly the upper 0.3 m of the soil. Analysis of the spectral peaks for potassium, thorium and uranium provides an indication of the degree of weathering and the amount of clay present. High K counts can also be associated with unweathered feldspars so ground truth is necessary to distinguish between weathered (clays) and unweathered (rock) material when these occur.

3. Direct measurement or sensing of electrical conductivity can be carried out with electrodes in the form of disc coulters (e.g. Veris 3100™ Soil Mapping System). Two to three pairs of coulters are mounted on a toolbar; one pair applies electrical current into the soil while the other two pair of coulters measure the voltage drop between them. The configuration of the VERIS 3100 sensors integrates soil EC in two depth ranges, 'shallow' (0-30 cm) and 'deep' (0-90 cm). This type of measurement depends on salinity, soil moisture content, texture and temperature correction.

Standards required for the recording and use of EMI remote sensing information

O'Leary (2006) has prepared comprehensive guidelines as a standard for "measurement, recording and interpretation" in electromagnetic induction mapping for the grains industry. These are briefly summarised below for the following aspects of the survey:

1. Survey objectives

Survey criteria will differ between research and commercial applications in the use of the technology.

2. Design criteria

Spacing should be matched to end use and speed according to the prevailing conditions (without jolting – max 25 km/hr). Water content is important because:

(a) at field capacity the soil solution is relatively well connected between pores and salts are mobilised without additional dilution,

(b) at very low water content connectively is reduced lowering conductivity and precision, and

(c) at saturated water content salts are diluted and the soil surface conditions are not appropriate.

3. Instrument set-up and adjustment

The main supplier of geo-survey equipment is Geonics Corporation Ltd. Technical operation of the instruments needs to follow the manufacturers directions for correct calibration to minimise drift caused by temperature, changed survey conditions and any drop in voltage of the power supply.

4. Fundamental data set

Volumetric units are recommended for soil descriptors relating to EM38 values. The type of equipment used, its settings and GPS type and position geo-referencing should be noted according to a suggested general protocol, which includes aspects such as:

- Grid lines parallel to the longest boundary,
- Transport and operation of equipment is carried out safely, with regard to hygiene quarantine and, pest and disease contamination,
- All physical settings for equipment documented such as antennae location, height and mounting position of sensors on the survey record,
- All electronic settings documented including GPS capture lag, differential signal and logger lag and,
- Data storage files named according to "site-crop-year-attribute" and method of mapping documented with the raw data in comma delimited format.

5. Data management and processing (real-time and post processing)

Presentation and reporting of data to include minimum, median and maximum according to consistent colours with monochrome red colour ramps for EC_a to distinguish from other data types such as Normalised Difference Vegetation Index (NDVI) and gamma radiometrics.

6. Soil testing design should meet the purpose of the survey cover the range of readings available and have documented GPS logged location.
7. A code of ethics is followed to enhance the reputation of practitioners and paddock surveying technology for farming business and natural resource management.

Different approaches to spatial analysis of EM data

Measurements of EC_a using the EM38 have been assessed and compared using a wide variety of different approaches (Table 8). In drier environments, high pH, salinity and boron constraints are important with high correlations of $R^2 = 0.95$ found for chloride, where a krigging grid of 10 m X 10 m was used on data position-corrected for ground speed and offset (O'Leary *et al.* 2003). However, the error in position due to ground speed is somewhat self-correcting on the return of each survey pass when the data is grided. Contrasting correlations were found for soil pits (R^2=0.0577) against root available water in mallee environments (Davies 2004; Nuttall 2001). Values of correlation coefficients used in different studies and environments were consistent across several different methods of spatial analysis (Table 8).

A positive correlation between EC_a and yield existed where clay content was assessed semi-qualitatively using a simple classification tree (Anderson-Cook *et al.* 2002). Rampant and Abuzar (2004) also achieved high correlation values using this method together with topographic variables (Table 8). The decision trees allocate variables to range space and the more complex the relationship between the response and the causative factors the greater the number of classification areas (Anderson-Cook *et al.* 2002). Groupings of variables can then be tested against predictions according to the crop yield. The classification method provides an error estimate of the percentage misclassification. Results obtained by Rampant and Abuzar (2004) for a paddock in the Mallee confirmed that the primary temporal variation was due to interaction between soil and landscape properties but could not explain how they interacted. Yield zones were delineated into six classes using coefficients of variation as either low, moderate or high temporal stability or low, moderate or highly unstable, respectively. These were sorted into common combinations using a classification tree. Apparently the combination of the deep EM31 with EM38 enhanced prediction of soil type in the 1.5 m depth zone by 15-22% misclassification errors, which was reduced to 10% by adding the radiometric data. The errors declined further to less than 3% with elevation and to 1.4 % with all the spatial layers together.

Linear relationships found between EM38 and crop yields were variable from year to year and were low to moderate (e.g. O'Leary *et al.* 2003; Table 8). A common recommendation was that each paddock surveyed needs a separate calibration due to soil and management history. Pedler *et al.* (2003) concluded that as yields were found to be negatively correlated with transects of EC_a (Table 8), zonation could be estimated from targeted EM38 readings to effectively manage landscape and subsoil conditions. Post-harvest EM38 surveys depend on terminal drought conditions and absence of intervening rainfall, which can reduce the stability of correlations with yield.

Research and industry needs for spatial identification of subsoil constraints

Commercial providers of paddock survey services are readily accessed in most areas of the HRZ. However, to take advantage of this information further research is needed to create user friendly spatial analysis tools. Industry capability can be improved through training and competency in spatial software and data interpretation by agribusiness (agricultural consultants, resellers, input providers).

More farmers and contractors collecting and utilising yield maps is required to boost the available databases for spatial assessment. This process needs a set of operating standards similar to those recently produced for EM surveys (O'Leary 2006).

O'Leary *et al.* 2004 have determined optimal transect spacing for use of paddock based EMI surveys in the Murray Mallee from the marginal cost of standard errors of (ECa) with change in transect spacing (10-150 m). Field productivity and variance in ECa determined the optimum range between 30-60 m. Marginal cost analysis against the cost of EM mapping (fixed at $5.55/ha) was used to determine the optimal transect spacing. These costs are likely to be similar for the HRZ except for difficulty with areas of surface rocks.

Table 8. Examples of correlation coefficients for measured EC_a and explanatory variables including soil properties and crop yields determined using different types of analyses in a range of environments.

Survey data type	Method of analysis	Explanatory variable	Variability measure (area classification %; correlation r, or r^2)	Reference
EC_a (EM38v, EM38h, EM31), rad. K, relative elevation	Classification tree (See5)	Crop yield (wheat)	18-53% area misclassified (each data type)	Rampant and Abuzar (2004)
Soil pit, EC_a (EM38v)	Universal kriging	Root available water (RAW)	r^2 = 0.0577 (RAW to 0.35 m, whole site)	Davies (2004)
EC_a (EM38v), DEM	Transect, paired samples	Wheat yield: N difference	r=-0.50 vertical r=-0.48 horizontal	Pedler *et al.* (2003)
EC_a (EM38v, EM38h)	Punctual kriging	Soil chemistry	Soil water: r^2 = 0.61-0.93 soil chloride:r^2 = 0.71-0.95	O'Leary *et al.* (2003)
EC_a (EM38v, EM38h)	Punctual kriging	Crop Yield	Barley 1999: r^2 = 0.25 Triticale 2000: r^2 = 0.31 Wheat 2001: r^2 = 0.08	O'Leary *et al.* (2003)
EC_a (EM38h)	Classification tree	Soil type	'Bojac' soil type, no-till wheat: EC_a alone explained 87.2 % of variability	Anderson-Cook *et al.* (2002)
EC_a (EM38v, EM38h) soil horizon layers	Linear regression	Topsoil depth	Vertical mode : r = 0.80 Horizontal mode: r = 0.61	Sudduth *et al.* (2001)
EC_a (EM38v, EM38h)	ESAP v2 and ANOVA	Soil chemistry (EC_e,)	Vertical mode (0-1.2 m depth): r = 0.78 Horizontal mode (0-1.2 m depth): r = 0.74	Corwin *et al.* (2003)
EC_a (EM38v, EM38h)	ESAP v2 and ANOVA	Soil chemistry (clay content)	Vertical mode (0-1.2 m depth): r = 0.25 Horizontal mode (0-1.2 m depth): r = 0.29	Corwin *et al.* (2003)
EC_a (EM38v), DEM	Ordinary kriging (spherical model)	Soil properties (clay content 0-80 cm)	Vertical mode: r^2 = 0.72 Horizontal mode: r^2 = 0.65	Hedley *et al.* (2004)
EC_a (EM38v), DEM	Ordinary kriging (spherical model)	Soil properties (CEC 0-50 cm)	Vertical mode: r^2 = 0.53 Horizontal mode: r^2 = 0.59	Hedley *et al.* (2004)

4.2 Description of method used to select sites for survey

The methodology used to establish relationships between subsoil conditions and crop yields was a compromise between a) the need to sample a dominant soil type in the landscape of the agro-ecological zone with a range of geographic features, b) the resources available and c) satisfactory data sets. An important prerequisite was for sites to have yield maps that allow appraisal and interpretation of surveyed subsoil conditions and crop yield. Yield maps were not commonly available and there is scope for greater resources to be made available for this kind of analysis. Selection criteria included good local representation of surrounding landscape features within the paddock. Site assessments were carried out at the properties in consultation with each of the farmers involved prior to commencing surveys.

The farmer groups provided paddocks well documented with soil samples and yield data that could be compared to that gathered in this study. Each of the farmer groups were contacted with information about the project and following either separate group discussions and/or presentations by project staff at group research committee meetings, coordinators provided a short list of sites. Initially, either group coordinators, executive officers or current leaders of each group were approached. The key contacts identified were Kirrily Condon (coordinator, Farmlink-NSW), Col Hacking (CEO, Southern Farming Systems), Una Allender (coordinator, Southern Farming Systems–Lake Bolac), Ken Solly (coordinator, Mackillop Group-SA) and Adam Inchbold (President, Riverine Plains Inc.). On ground assessments and consultations were conducted by Philip Newton, and the technical aspects of the paddock level surveys in the field were carried out by DPI staff Paul Rampant and Grant Boyle with the assistance of Philip Newton. Surveys were carried out in late summer and early autumn of 2005 at Marrar (14–15 February), Yarrawonga (16–17 February), Willaura (18–19 April) and Frances (20–21 April).

4.3 Detailed site survey methodology

Paddocks were remotely sensed with inductive electromagnetic sensors (dipolar EM38 –vertical 1.5 m and horizontal 0.75 m depth averaged and EM31 MK 2–3 m depth averaged) and gamma detection radiometer (Exploranium™ GR 320 gamma spectrometer) mounted on a four–wheel all terrain vehicle (ATV) (Figure 19). Spatial position was determined using real–time differential geographic position system (Navcom™ DGPS–subdecimetre accuracy) and data linked to position was captured in an on–board computer with navigation screen (inset Figure 19). At each site, either a single paddock of *c*. 60 ha or two smaller paddocks of similar area were surveyed.

The surveys were carried out in late summer and early autumn after heavy rains. This timing aimed to identify the depth to subsoil clay, which was thought would be better discriminated by the rapid evaporation of less tightly held water from the surface topsoil. Other times are useful for measurement, such as soil water remaining immediately after harvest for detecting toxic or physical limitations to root growth, or during winter at field capacity to identify any salinity but these factors were also part of the soil sampling and testing regime. Survey lines were 20 m apart in all paddocks and approximately two days per site were needed to set up, survey, soil sample and travel.

4.4 Paddock scale data processing and mapping

Due to different harvester management, some paddocks did not have yield data sets which entirely corresponded with the area surveyed. Also, some of the variability in yields was an artefact of sampling. In the case of canola crops, it was evident from studying yield values and their associated GPS fixes, that the harvester was at times, sampling two windrows and not one. In cereal crops, it was evident from studying yield values and their associated GPS fixes that the harvester did not cut a full swath while travelling in a curve, i.e. turning at headlands or avoiding obstacles.

Survey data were initially processed using proprietary software associated with each instrument to obtain point data representing electrical conductivity, yield and gamma spectra. Spatial analysis of this point data was conducted using Arcview 3.3a and Spatial Analyst 1.1™

(Environmental Systems Research Institute, Incorporated). Smoothed surfaces, in a raster format, were interpolated using the inverse distance weighting method. Values for yield, salinity and potassium content were taken from raster cells corresponding with the intact cores taken along the transects at each site, and their relationships were studied using GENSTAT v8.0 to derive correlations between variables and regressions with distance.

Figure 19. ATV mounted remote sensing equipment used to survey paddocks.

4.5 Soil Sampling

Intact soil cores were taken at each site, along at least two transects each with a minimum of 10 samples spaced 30 m apart, and generally in down–slope direction (Figure 13). Where the survey data was not available the transects were selected based on slope and location in the landscape. The intact soil cores were taken to a depth of 110 cm, or shallower if rock was struck or subsoil was impenetrable (Figure 19). Each core was extracted within a clear plastic polycarbonate tube sealed at each end with airtight plastic caps. Cores were stored at or below 0°C until examined and described (McDonald *et al*.1990). Soil samples were taken from each intact core: a 10 cm section was taken at depths of 0–10, 20–30, 45–55 cm and at the last 10 cm (usually the 100–110 cm depth).

4.6 Soil Analysis

Soil samples were air-dried at 40°C and ground to pass through a 2 mm screen. All samples were analysed for pH in water and 0.01 M $CaCl_2$, and electrical conductivity (Rayment and Higginson, 1992; Methods 4A1, 4B2, and 3A1, respectively). Sub-samples were ground to pass a 1 mm sieve and analysed using mid-infra-red spectroscopy (MIRS) as a predictor for several physico-chemical characteristics. Spectra were submitted to CSIRO laboratory in Adelaide for interpretation against their MIRS calibration data. Eleven cores were selected (2 from Willaura and 3 from each of the other sites) to provide forty-four soil samples for conventional analysis to cross check MIRS predictions.

Basic properties of soil cores were described, e.g. field texture, colour, carbonate, segregations (McDonald *et al.* 1990). Aggregate stability upon immersion in water was assessed; i.e. dispersion of clay was observed in natural and remoulded fragments on each core at depths of 25 cm and 50 cm, after 10 minutes and 12 hours.

Figure 20. Geoprobe™ soil sampler used for obtaining polycarbonate encased soil cores for analysis.