10.1071/CP08459_AC

Accessory Publication: Crop & Pasture Science, 2009, 60(11), 1031–1043.

Accessory Publication to the paper:

Dalgliesh NP, Foale MA, McCown RL (2009) Re-inventing model-based decision support with Australian dryland farmers: 2. Pragmatic provision of soil information for paddock-specific simulation and farmer decision making.

Procedures for determination of soil properties and states relevant to crop simulation and farmer crop management decision making.

1. Determination of Plant Available Water Capacity (PAWC)

The procedures used in FARMSCAPE were described by Carberry *et al.* (1996) in relation to research between 1978 and 1990 at Katherine, Northern Territory, where in-situ field soil characterisation techniques, as described by Ratliff *et al.* (1983) and Ritchie *et al.* (1986), were used to specify inputs to the APSIM model. Technically therefore, there was little new in FARMSCAPE's (Carberry *et al.* 2002) soil measurement methods. The main advances were (a) farmers' adoption of the soil water balance concept and associated soil measurements and (b) pragmatic systems of measurement and data handling to minimise costs. Advisers/consultants also had an interest and involvement in these developments, seeing the potential for provision of additional services to their clients if warranted. For this demand to be met, however, required data systems that provided ready access to geographically located soil information.

1.1 Measurement of Drained Upper Limit

Whilst the techniques used in FARMSCAPE were based on those used at Katherine (Carberry *et al.* 1996) and described by Ratliff *et al.* (1983) and Ritchie *et al.* (1986) a number of important adaptations were made, some of which were suggested by farmers involved in the project. These were necessary to overcome problems of inherently slow water infiltration on the swelling clay soils of the region (Williams 1983) and issues of soil surface slaking resulting from the too rapid application of a large volume of water using flood or sprinkler irrigation (Dalgliesh and Foale 1998). The solution was trickle irrigation. A trickle system was established on a 16 m^2 area of soil, covered with plastic sheeting (using 100 µm thick black polythene) sealed around the edges and water applied under gravity at a rate of 200 L per week (Burk and Dalgliesh 2008). Water recharge and drainage were monitored using a neutron moisture meter (NMM) which required prior installation of an access tube in the centre of the site to a depth of 180cm. (Dalgliesh and Foale 1998, Hochman *et al.* 2001). Once it was judged that the soil was thoroughly wet, it was allowed to drain until NMM monitoring indicated minimal change in profile water status. Samples for gravimetric moisture content and bulk density were then taken.

Because drainage in Vertosols is slow and may continue for long periods (Bridge 1981), the point at which water content at DUL is measured is a matter of judgement based on when drainage rate has reached a sufficiently low level to ignore. In the high clay soils (clay contents between 50 and 80%), it was common for 'wetting-up' to be undertaken for a period of 3 to 6 months before the profile had been wet to the potential depth of crop rooting and had time to drain sufficiently for sampling to take place.

In the shrink/swell soils (i.e. Vertosols) gravimetric water content was determined from three 50mm diameter soil cores sampled within the experimental area to the assumed depth of rooting. In rigid soils, sampling for gravimetric moisture content at DUL was undertaken in conjunction with the measurement of bulk density, discussed below. In both cases samples were divided into 7 standard sampling depth increments of 0-15, 15-30, 30-60, 60-90, 90-120, 120-150 and 150-180 cm.

1.2 Measurement of Crop Lower Limit

The determination of crop lower limit (CLL) requires the measurement of soil water status after a crop has extracted all of the water it is capable of extracting and is practically dead or terminally wilted (Ratliff *et al.* 1983). To ensure that late season rains did not interfere with dry-down, a rain-exclusion tent was installed over an area of actively growing crop (9 m^2) at around the time of flowering, and remained in place until sampling for gravimetric moisture content at crop maturity (Dalgliesh and Foale 1998; Burk and Dalgliesh 2008). The tent cover was fabricated from a translucent, woven plastic material designed for shade house use. The tent was designed to exclude rain, but to maintain temperature, humidity and radiation at levels similar to those in the adjoining, uncovered crop. To specify water distribution in the potential crop rooting zone, and to act as a benchmark for actual rooting depth at crop maturity, gravimetric moisture content was measured to full potential rooting depth at the time of tent installation. The difference between this measurement in each layer and that at crop maturity indicated both the extraction capability of the crop and the depth to which extraction took place. At crop maturity three cores were sampled from the centre crop row under the rain exclusion tent to determine gravimetric moisture content in the seven standard depth increments, unaffected by any late rainfall that may have occurred.

As the top two soil layers (0-15 and 15-30 cm) were generally affected by evaporation resulting in moisture contents below the lower limit of crop extraction, the judgement was made that measured data for these layers be replaced by the CLL value determined for the third soil layer (30-60cm). It is considered that this procedure is valid for soils of uniform texture but would not be appropriate for duplex soils or those with a strong gradational profile. Where moisture characteristics were determined for more than one crop on a particular soil type, the moisture contents in the top two layers were standardised for all species, taking the value for the third layer for the crop that produced the lowest volumetric moisture as the norm. This technique is supported by Ratliff *et al.* (1983) who found only minor differences between crop species in their ability to extract water from the top layers of the soil profile. He considered this to be a result of root length density in the zone exceeding a critical limit for access to all available water in the soil volume.

1.3 Determining Bulk Density

PAWC in millimetres of available water is calculated as the difference in volumetric water content between DUL and CLL. Calculation of volumetric water content at DUL and CLL (cm^3 water/cm^3 soil) is done by multiplying the gravimetric measurements (g water/g oven dry soil) by the bulk density (BD) (g oven dry soil/cm^3 oven dry soil) (Dalgliesh and Foale 1998).

In rigid soils (where air filled porosity increases as the soil dries) BD does not change with moisture content and may be measured at any time. However, for ease of sampling, BD was measured in conjunction with DUL (Dalgliesh and Foale 1998; Burk and Dalgliesh 2008).

Sampling was undertaken using a large diameter sampling ring (~75 mm) and a hand operated sampler using the process depicted in Figure 1. Sampling sites at layer intervals down the profile were accessed using a 20-25cm diameter auger to remove the overburden (Fig. 4A) (Talsma and van der Lelij 1976, Bridge 1981; Burk and Dalgliesh 2008). The base of the hole was levelled using a tool attached to the auger shaft and the sample taken using a sampler in which the sample ring is inserted into the sampler head and driven into the soil using a sliding hammer which moves vertically along the guide shaft and is operated by attached ropes (Fig. 4B). Once a particular depth sample has been taken, the process is repeated by augering to the next depth layer, levelling and sampling. Datum pins located at the soil surface prior to sampling provide a datum for accurate depth measurements.

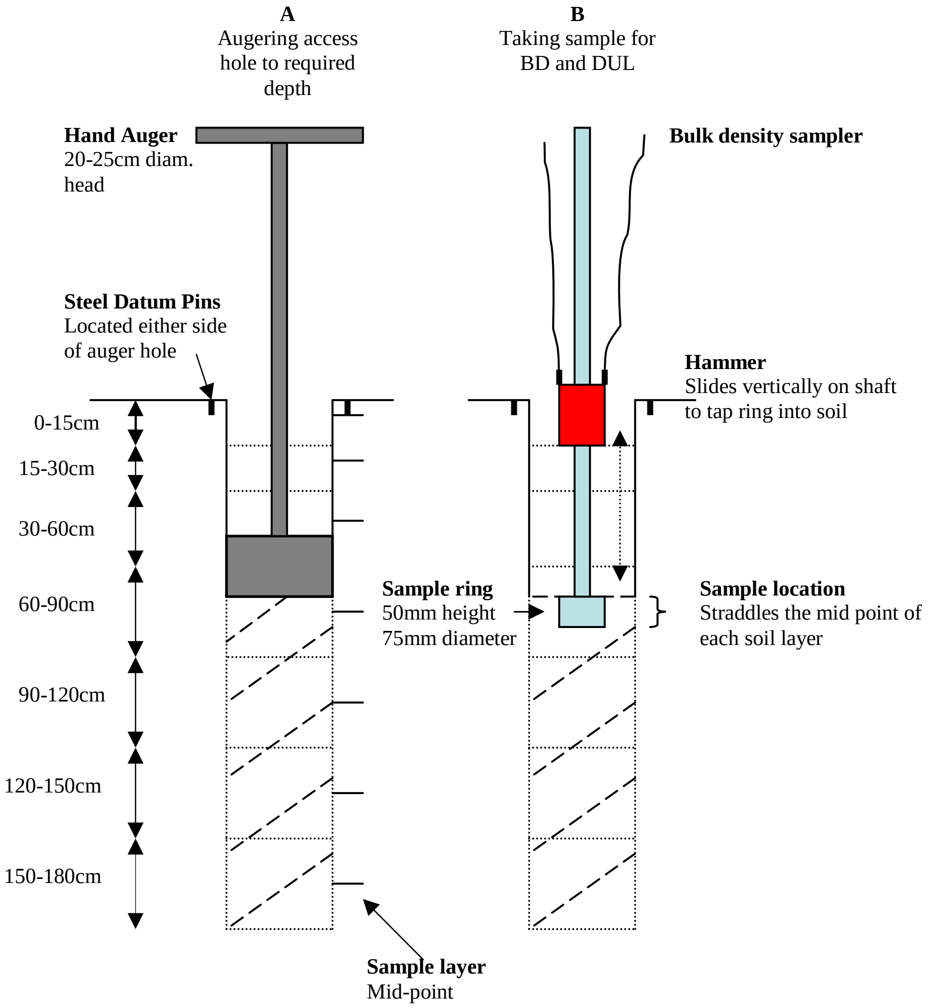

Figure 1: Schematic of hand coring process for BD (and for DUL).

Soils that exhibit shrink/swell characteristics, such as Vertosols, present special challenges in describing soil water behaviour in terms of DUL and CLL. Unlike rigid soils, in which the BD and total porosity remain constant and the relative fractions of air filled and water filled porosity vary in close inverse relation, in shrink/swell soils total porosity varies with change in water content (as peds and fine particles move closer together as the water is removed), with air filled pore space remaining relatively constant (Bridge and Ross 1984). Data from 50 soils of the northern cropping region (Dalgliesh and Foale 1998) show a close relation between the measured BD and the gravimetric water content of the wet soil, corresponding to an air filled porosity of 3.2% (BD= $(1\text{-}0.032)/(1/2.65+\theta_g)$; $R^2 = 80.8\%$). This confirms that the soils are exhibiting shrink/swell characteristics and enables BD to be calculated, as a more satisfactory approach than measurement, for this type of soil. To use the equation BD (g/cc) = $(1\text{-e})/(1/\text{AD}+\theta_g)$, where e = air filled porosity at θ_g , AD = absolute density of the solid matter in the soil (assumed 2.65 g/cc) and θ_g = gravimetric water content (g/g) of wet soil, assumptions are made about notional air filled porosity at water contents corresponding to DUL and SAT. A value of 3% has been assumed at SAT and a value of 5% for drainable porosity SAT-DUL. Thus the measured gravimetric water at assumed DUL permits calculation of BD. Bulk densities used in simulations conducted in FARMSCAPE, on shrink/ swell soils, were calculated in this way, with increases in BD due to shrinkage, as the soil water content dropped below DUL, being ignored (Berndt and Coughlan 1976; Gardner 1985; Burk and Dalgliesh 2008).

1.4 Calculating Plant Available Water Capacity (PAWC)

PAWC (mm) for each layer of the soil profile is calculated using the formula: PAWC (mm) = (DUL-CLL) x Depth Increment (mm) where DUL and CLL are expressed as a fraction (cm^3 water/cm^3 soil). PAWC for the soil profile is the sum of the PAWC for the individual soil layers (Burk and Dalgliesh 2008).

1.5 Calculating profile Plant Available Water (PAW)

Plant available water (PAW) is described as the water available for crop use at a particular point in time. It is generally determined through soil coring and is calculated using the formula: PAW = Current water content – CLL (cm^3 water/cm^3 soil) for each soil layer. Total PAW for the soil profile is the sum of the PAW for the individual soil layers.

2. Monitoring soil water and nitrate nitrogen

2.1 Sampling intensity

The monitoring of the status of soil nitrate nitrogen and other nutrients, especially phosphorus and zinc, has become standard practice in the northern cropping region (Lawrence *et al.* 1996). The value of this information has risen as age of cultivation and cropping intensity have increased and organic carbon run-down has occurred (Dalal *et al.* 1996). In commercial practice farmers commonly take three bulked cores to a depth of 10, 30 or sometimes 60 cm to represent paddocks ranging in size from 50 ha to more than 500 ha (Castor and Associates, Goondiwindi, pers. com.).

In FARMSCAPE it was important to know the cost-benefit relationships pertaining to decisions to intensify soil sampling. Researchers concerned with the feasibility of core sampling for enhancing farmers' monitoring, needed to know the effect of sample location number (sample size) on the variance of a paddock mean value. An analysis of sampling intensity undertaken on four fallowed heavy clay soils in the Dalby district on the Darling Downs (Jones 1994), showed that the number of sampling points (one core per point) required to provide soil water and nitrate nitrogen information, at a reasonable level of accuracy and confidence, was significantly higher than normally undertaken in commercial practice (Table 1). This study was undertaken on one Black and three Grey Vertosol soils and included data generated at 46 sampling sites and 7 soil layers from 0 to 180cm depth. The analysis also provided insight into differences in degree of variability between soil water and nitrate nitrogen, revealing that less intense sampling is required for soil water determination when aiming for a similar level of confidence and accuracy.

As a result of this research, a pragmatic sampling strategy was implemented within FARMSCAPE where ten cores were specified from a paddock of 100 hectares. This resulted in sampling at an accuracy of better than +/–20% and a confidence level of 90% for nitrate nitrogen, and slightly less than 80% confidence and +/–1% accuracy for soil water.

Confidence level	**Nitrate Nitrogen**	**Water**
	Cores required for medium level of accuracy	
	+/-20% of mean	**+/-2% of mean**
66%	3	2
80%	5	3
90%	8	5
	Cores required for higher level of accuracy	
	+/-10% of mean	**+/-1% of mean**
66%	10	7
80%	18	12
90%	29	20

Table 1: Sampling points, at two levels of accuracy and three levels of confidence required to sample a paddock to a known level of accuracy.

2.2 Sampling depth

In addition to the importance of intensity of sampling, depth of sampling also impacts on how well available resources within the rooting zone are described. As indicated, local commercial practice has been to sample the surface layer to a depth of 10 or 20 cm , or at most 60 cm. However, because models require information on soil resources to potential rooting depth, from the researchers’ standpoint it was important that sampling in FARMSCAPE was done accordingly. For deep-rooted annuals such as wheat, sorghum and cotton, sampling was undertaken to a depth of 180 cm, and for shallower-rooted, short-season crops such as mungbean, to 120 cm. In addition, the number of sampling layers was increased to seven, according to the following list of depths: 0-15, 15-30, 30-60, 60-90, 90-120, 120-150 and 150-180 cm.

Although depth and vertical resolution were important to specify and test simulation models, it was anticipated that farmers would pragmatically reduce this intensity in order to reduce the cost of analyses, by either combining layers or reducing the depth of sampling.

2.3 Sampling equipment

Suitable equipment for more intensive routine soil sampling is essential for its adoption. Farmers had several alternatives for intensification: (1) contract soil sampling to an advisor with appropriate equipment, (2) purchase a coring rig, (3) build one's own coring rig, or (4) purchase a simple manual sampling kit.

The development by Grevis-James (1974) of a vehicle-mounted hydraulic soil sampling rig revolutionised monitoring of water and nutrients in experimental research on the Darling Downs. Whilst design modifications have continued over the past 35 years, current sampling rigs still use the underlying principle of hydraulic power to push thin walled steel coring tubes into the soil (Dalgliesh and Foale 1998). Current rigs are designed to be attached to either a road vehicle or a tractor, and they enable the sampling of a paddock, at a commercially feasible cost (Figure 2). The hand-operated sampling kit, comprising a coring tube, wooden hammer and extraction jack (Figures 3 and 4) (Foale and Upchurch 1982) was developed in this project to enable farmers and advisers to explore their own soil without significant investment in specialised machinery. This simple and cheap kit (approx. A$200) is suitable for sampling to 180cm in two stages using two thin-walled tubes (a 37 mm diameter tube to 1 m depth followed by a 32 mm diameter tube to 180 cm). This kit is useful in allowing practitioners to physically examine the soil profile, which was previously quite difficult. This technology opens up the opportunity to investigate issues such as soil depth, location of wetting front and rooting depth, and is useful in calibrating the 'push probe'. This is done by making a comparison of 'depth of wet soil' observed in the core with the changes in 'feel' or resistance of the probe as it is pushed into the soil.

Figure 2. Soil coring rig attached to a tractor and utilising its hydraulic system to push thin walled coring tubes to a depth of 1.5 to 1.8 m.

Figure 3. Soil hand coring kit comprising thin walled coring tube (1 m length), extraction jack and wooden hammer.

Figure 4. Extracting a core from a depth of 1 m using the extraction jack.

The type of sampling equipment selected for a job will depend on a number of factors, including the quantity of sampling to be undertaken, the convenience of owning equipment, and the cost. Construction plans for the tractor-mounted farm unit and the road vehicle-mounted unit were drawn up as part of the FARMSCAPE project. The plans of the tractor mounted unit were provided to farmers, a number of whom built their own rigs, either as individuals or in neighbourhood consortia, for under A$2000. Plans for the commercial unit were made available to a local engineering company that has been manufacturing the unit for the past 10 years at a cost of approx. A$8000 (R. Milne, Milne Industries, pers. com.). A number of other local companies have entered the market more recently based on demand from the consulting fraternity for suitable sampling equipment. Design drawings for the hand sampling equipment are provided in the manual 'Soil Matters' (Dalgliesh and Foale 1998) and a complete kit is manufactured commercially in Toowoomba. In spite of the equipment that is available for efficient soil sampling, the decision, from the farmers' perspective, on whether to invest is often not a difficult one as many advisers do not charge directly for soil monitoring, but include the cost in the price of consumables sold to the farmer.

References

Berndt RD, Coughlan KJ (1976) The nature and change in bulk density with water content in cracking clay. *Australian Journal of Soil Research* **15**, 27-37.

Bridge BJ, Ross PJ (1984) Relations among physical properties of cracking clay soils. In ‘Properties and Utilisation of Cracking Clay Soils. Reviews in Rural Science’. **5**, pp. 97-104. (Uni of New England: Armidale, NSW)

Bridge BJ (1981) Site characterisation for field experiments – Soil physical aspects. In ‘Notes for Refresher Training Course on Interpretation of Plant Response and Adaption to Agricultural Environments’. 2-6 Feb. 1981. (Australian Institute of Agricultural Science: Brisbane)

Burk L, Dalgliesh NP (2008) ‘Estimating plant available water capacity.’ (Grains Research and Development Corporation: Canberra)

Carberry PS, McCown RL, Muchow RC, Dimes JP, Probert ME, Poulton PL, Dalgliesh NP (1996) Simulation of a legume ley farming system in northern Australia using the agricultural production systems simulator. *Australian Journal of Experimental Agriculture* **36**, 1037-1048.

Carberry PS, Hochman Z, McCown RL, Dalgliesh N, Foale MA, Poulton PL, Hargreaves JNG, Hargreaves DMG, Cawthray S, Hillcoat N, Robertson MJ (2002) The FARMSCAPE approach to decision support: farmers', advisers', researchers' monitoring, simulation, communication and performance evaluation. *Agricultural Systems* **74**, 141-177.

Dalal RC, Strong WM, Weston EJ, Cooper JE, Lehane KJ, King AJ, Chicken CJ (1996) Sustaining productivity of a Vertisol at Warra, Queensland, with fertilizers, no-till, or legumes. 1. Organic matter status. *Australian Journal of Experimental Agriculture* **35**, 903-913.

Dalgliesh NP, Foale MA (1998) ‘Soil matters-Monitoring soil water and nutrients in dryland farming systems.’ (CSIRO/Agricultural Production Systems Research Unit: Technical Manual-ISBN 0 643 06375 7).

Foale MA, Upchurch DR (1982) Soil coring method for sites with restricted access. *Agronomy Journal* **74**, 761-763.

Gardner EA (1985) Identification of Soils and Interpretation of Soil data, In ‘Soil Water’. pp. 197-234. (Australian Society of Soil Science Inc., Qld Branch: Brisbane)

Grevis-James IW (1974) An hydraulic soil sampler. *Queensland Journal of*

Agricultural and Animal Sciences **31**(1). (Queensland Department Primary Industries: Brisbane)

Hochman Z, Dalgliesh NP, Bell K (2001) Contributions of soil and crop factors to plant available water capacity of annual crops on black and grey Vertosols. *Australian Journal of Agricultural Research* **52**, 955-961.

Jones PN (1994) Sample size for on-farm soil sampling. CSIRO Division of Tropical Crops and Pastures, IPP&P Biometrics Report (IPPP/BU/94/15), Brisbane.

Lawrence DN, Cawley ST, Cahill MJ, Douglas N, Doughton JA (1996) Soil nitrogen decision aid puts farmers in control. In 'Proceedings of 8th Australian Agronomy Conference'. (Ed. M Asghar) pp. 369-372. (Australian Society of Agronomy: Toowoomba)

Ratliff LF, Ritchie JT, Cassel DK (1983) Field measured limits of soil water availability as related to laboratory-measured properties. *Soil Science Society American Journal* **47**, 770-775.

Ritchie JT, Kiniry JR, Jones CA, Dyke PT (1986) Model inputs. In 'CERES-MAIZE. A simulation model of maize growth and development'. (Eds CA Jones JR Kiniry) pp. 37-49. (Texas A&M University Press)

Talsma T, van der Lelij A (1976) Infiltration and water movement in an in situ swelling soil during prolonged ponding. *Australian Journal of Soil Research* **14**, 337-349.

Williams J (1983) Physical properties and water relations: Soil hydrology. In 'Soils: An Australian viewpoint'. pp. 499-530. (CSIRO/Academic Press, Melbourne)