CSIRO Land and Water

Soil Water Measurements at the 2004 Marrar Grazing Wheat Trial

Warren J Bond

CSIRO Land and Water, Canberra

CSIRO Land and Water Client Report

February 2005

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Cover Photograph:

Description: Wireless logger antennae in the three plots monitored in Rep 1 of the 2004 Marrar Grazing Wheat Trial
Photographer: Warren Bond

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Acknowledgements

The work described in this report was commissioned by FarmLink Research as the host agency for Murrumbidgee Grain & Graze, in collaboration with the Murrumbidgee Catchment Management Authority (MCMA), NSW Agriculture, CSIRO and Charles Sturt University. Grain & Graze is a national research program funded by GRDC, Land & Water Australia and MLA.

The assistance of John Pattison, on whose property Takada the trial was carried out is gratefully acknowledged, as is that of Kirrily Condon (FarmLink Research and Communication Manager).

The author is also grateful for the assistance of Paul Hutchinson, Gordon McLachlan and Chris Drury (CSIRO Land and Water) in carrying out this project.

Executive Summary

Measurements of soil water potential were made for two replicates of three treatments in the 2004 Marrar Grazing Wheat Trial of the Murrumbidgee Grain & Graze project. The three treatments allowed the comparison of grazed or ungrazed Wedgetail wheat with a normal (ungrazed) spring wheat, Diamondbird.

The main conclusions drawn from the results were:

- the winter rain only penetrated to an average depth of 0.8 m across the plots
- there was evidence of strong soil water extraction by crop roots to at least 1 m, and some soil water extraction to 1.2 m, in all plots
- there were no strong treatment differences in the depth of wetting or depth of drying of the soil
- rate of soil drying, and therefore water use, by the grazed Wedgetail treatment was slower relative to the other treatments at and soon after the completion of grazing in August
- this slower water use in August/September had little effect on the total drying achieved by the grazed Wedgetail treatment, and it is inferred that there was little difference in total seasonal water use between the treatments
- this final conclusion may be affected by the dry seasonal conditions in which water use was controlled by soil water availability; in a wetter year, with excess available soil water, the results may be different

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1 Background and Introduction

The Marrar Trial is one of three Grazing Wheat Trials that form part of the Murrumbidgee Grain & Graze Project. The other trials are located at Yerong Creek and Grenfell. In each trial, six grazing wheat varieties are being compared: Whistler, Wylah, Wedgetail (grazed and ungrazed), Marombi, Mackellar and Lorikeet. These are being evaluated for dry matter production, feed quality, grazing recovery, water use (compared to a spring wheat, Diamondbird) and ground cover.

CSIRO Land and Water was commissioned to provide real-time monitoring of soil water status at the Marrar Trial, from which to infer water use. This report describes the measurements and results from the 2004 trial. The results are discussed in three sections:

- depth of penetration of the winter rainfall
- depth of soil drying by the crops
- comparison of water use between treatments

2 Overview of the Methodology

Measurements were made in six plots of the Marrar Grazing Wheat Trial: the Wedgetail (grazed), Wedgetail (ungrazed) and Diamondbird treatments in each of Replicates 1 and 4. They were carried out at one location, approximately the centre, of each 2.5 x 10 m plot.

The chosen soil moisture sensors were Watermark® gypsum blocks. These have the primary advantages of low cost, and ease of installation at depths up to 2 m or more. The prime disadvantage is that these sensors measure soil water potential, rather than soil water content, and soil water potential cannot be directly related to soil water storage in mm of water. Nevertheless, much useful information can be obtained, as described later in this report, at a substantially lower cost compared with reliable measurements of soil water content.

Sensors were installed at 0.2 m intervals from 0.2 m to 1.6 m below the soil surface prior to the sowing of the trial.

The sensors were measured with data loggers, one in each plot. To facilitate the ready availability of the data, the loggers were linked by radio communication to a receiver at the nearby shearing shed, which in turn communicated by cdma telephone link to a computer at the CSIRO Laboratories, from where the data were uploaded daily to a website. By this means, data from the previous day were usually available by 7 am each morning.

A more detailed description of the methodology can be found in Appendix A. In addition, some notes on interpreting the measurements are attached in Appendix B.

The complete data set for each plot is presented in Appendix C. Logger failures in both the replicates of the ungrazed Wedgetail replicates caused breaks in the data record, but these did not become severe until after the end of the growing season, and do not affect the interpretation of the results substantially.

3 Depth of soil wetting

The arrival of winter rainfall at individual depths can be seen quite clearly in the data traces (see Appendix C), particularly at the shallower depths. Wedgetail (grazed) Rep 1 provides a good example to illustrate this, as shown in Fig. 1. The first wetting at 0.2 m (end of May) and

0.4 m (end of June) was abrupt in both cases and readily apparent. Several other wetting events are clear at both depths up to early September. Wetting at 0.6 m was more gradual, though clearly commenced soon after the wetting at 0.4 m at the end of June and continued through to mid-August. At 0.8 m, wetting was again more sharply defined in early August. No wetting is apparent at 1.0 or 1.2 m. The gentle increase from August at both those depths is attributed to soil warming and the effect of the increasing temperature causing the sensor output to indicate an apparent wetting (as described in Appendix B). The shape and similarity of the trends at 1.0 and 1.2 m is confirmatory evidence that this was a temperature effect rather than wetting.

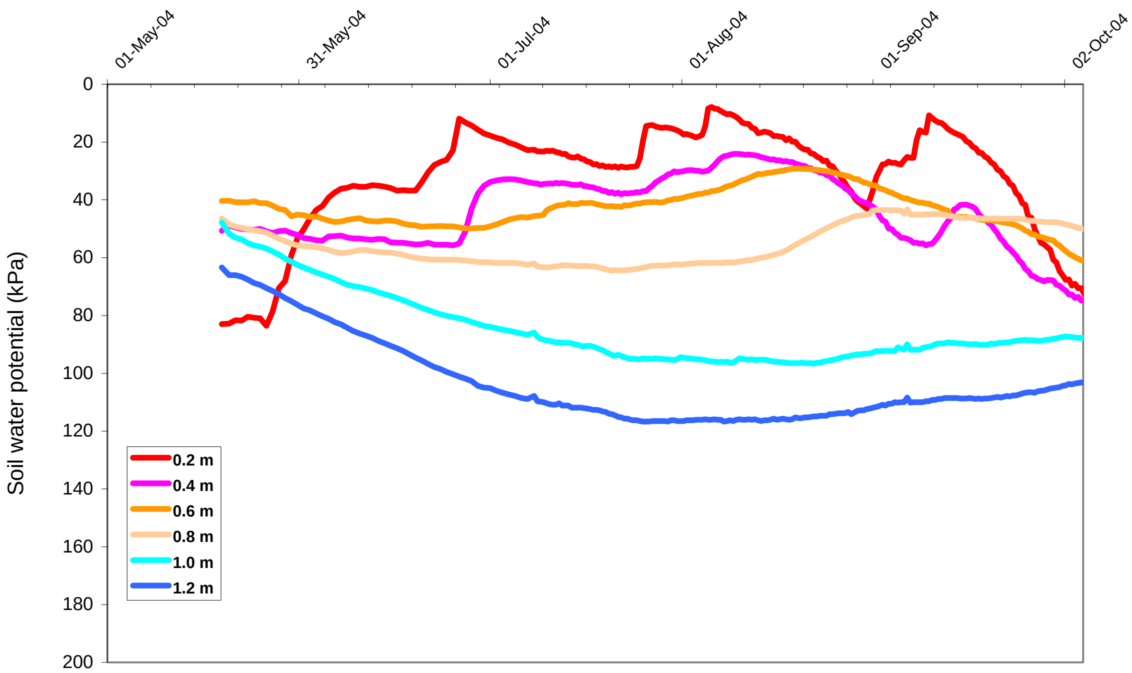


Figure 1. Soil water potential data for Wedgetail (grazed) Rep 1, showing profile wetting. The data were truncated at the end of September after which there was no further wetting apparent. Data from the deeper depths have also been omitted for clarity.

Examining the data in this way shows that the soil wet to 0.8 m in four of the plots, only to 0.6 in one and to 1.0 m in another, as summarised in Table 1. This is consistent with observations from other paddocks around the Wagga Wagga, Temora and Harden districts in 2004.

Table 1. Maximum depth of wetting in each plot.

Treatment	Wedgetail (grazed)		Wedgetail (ungrazed)		Diamondbird	
Rep	1	4	1	4	1	4
Depth of wetting (m)	0.8	1.0	0.8	0.6	0.8	0.8

4 Depth of soil drying

The soil water potential data also give a clear indication of how deep in the soil profile drying occurred. Unfortunately the WaterMark® sensors used for the measurements are capable of measuring accurately to only 200 kPa, which is somewhat less than the notional maximum crop drying potential (or "wilting point") of 1500 kPa. While the data therefore do not allow any statement about complete drying at a particular depth, they do indicate whether or not crop roots have reached that depth as evidenced by a sharp increase in the rate of drying. Table 2 summarizes the results of applying this criteria to the data in Appendix C. All plots were dried substantially to at least 1 m, with Rep 1 of the ungrazed Wedgetail treatment drying strongly to 1.2 m. There was some evidence of drying for 0.2 to 0.4 m below that but, with the exception of Rep 1 of the ungrazed Wedgetail, no evidence of significant drying at 1.6 m. An effective depth of root water extraction of 1.2 m is comparable to that observed at other sites in the Wagga Wagga region for a range of crops over a number of years.

Table 2. Extent of soil drying at the different measurement depths in each treatment.

Treatment	Wedgetail (grazed)		Wedgetail (ungrazed)		Diamondbird	
Rep	1	4	1	4	1	4
0.2	Drier than 200 kPa	Drier than 200 kPa	Drier than 200 kPa	Drier than 200 kPa	Drier than 200 kPa	Drier than 200 kPa
0.4	Drier than 200 kPa	Drier than 200 kPa	Drier than 200 kPa	Drier than 200 kPa	Drier than 200 kPa	Drier than 200 kPa
0.6	Drier than 200 kPa	Drier than 200 kPa	Drier than 200 kPa	Drier than 200 kPa	Drier than 200 kPa	Drier than 200 kPa
0.8	Drier than 200 kPa	Drier than 200 kPa	Drier than 200 kPa	Drier than 200 kPa	Drier than 200 kPa	Drier than 200 kPa
1.0	Drier than 200 kPa	Drier than 200 kPa	Drier than 200 kPa	Drier than 200 kPa	Drier than 200 kPa	Drier than 200 kPa
1.2	Some drying	Some drying	Drier than 200 kPa	Some drying	Some drying	Some drying
1.4	No significant drying	Some drying	Some drying	Some drying	Some drying	Some drying
1.6	No significant drying	No significant drying	Some drying	No significant drying	No significant drying	No significant drying

It is interesting that soil drying occurred even at depths where there had been no storage of water over the winter period. This suggests that there had been some storage of water in the profile prior to the commencement of measurements in May, and/or that the previous crop had not fully exploited the soil water store in 2003.

5 Comparison of water use between treatments

Until August, there was very little difference in the behaviour of the soil water potential traces in the different plots. Although different plots and depths had different starting points, measurements at the same depth changed in parallel to each other, once initial wetting had occurred, until August, as seen in Fig. 2 for 0.2 and 0.4 m. Although Rep 1 of Diamondbird at 0.4 m took longer to wet than other plots, once it did wet up it followed the same pattern.

In early August, however, once persistent drawdown of soil water by the crops started, the measurements from different plots started to diverge. This also corresponds with the time that grazing was completed.

Overall, the two grazed Wedgetail plots dried more slowly that the other treatments at both 0.2 and 0.4 m, as can be seen in Fig. 2. At deeper depths, there were no obvious differences in drying behaviour.

Given the correspondence of the decreased rate of drying with the cessation of grazing, when the leaf area of the grazed crop was at its smallest relative to the other treatments, it seems reasonable to attribute the slower drying (and therefore water use) to grazing.

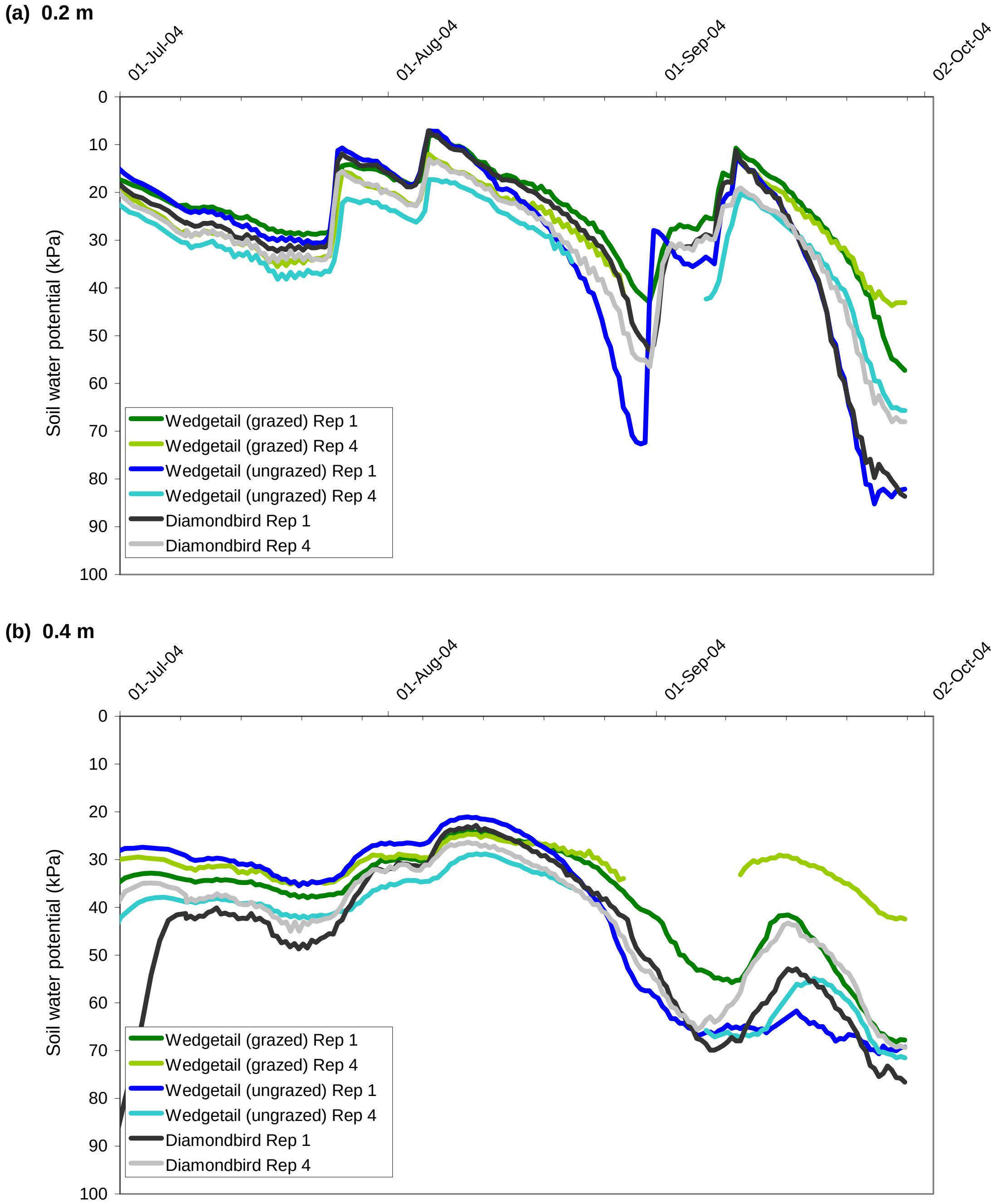


Figure 2. Comparison of soil water potential in all plots at (a) 0.2 m and (b) 0.4 m, showing the slower drying of the grazed treatments relative to the others between 1 August and 30 September.

By the end of October, when the drawdown of soil water was occurring rapidly at the shallower depths, differences between the plots had largely disappeared, although Rep 4 of the grazed Wedgetail continued to dry slower than the other plots. This is illustrated in Table 3, in which the date at which the soil water potential had dried to 200 kPa at each depth in each plot is presented. The grazed Wedgetail was the slowest to dry at 0.2 and 0.4 m in both Replicates. At deeper depths, there was little difference between the plots except for Rep 4 of the Wedgetail (grazed) which lagged behind the other plots by a few days.

It is concluded that while the grazing treatment affected the rate of water use immediately after grazing, by the end of the growing season the differences were small and the difference in overall water use between the different treatments is expected to have been small.

This conclusion may be affected by the dry season that was experienced in 2004, when water use was effectively limited by what was available in the soil rather than by crop performance. If the spring had been wetter, and soil water remained available throughout the growing season, the slower rate of water use by the grazed treatment may have carried through to reflect a lower total water use for the season. Results in future years may help clarify this.

Table 3. Dates at which the soil water potential at each depth in each plot reached 200 kPa

Treatment	Rep	0.2	0.4	0.6	0.8	1
Wedgetail (grazed)	1	19-Oct	19-Oct	27-Oct	02-Nov	08-Nov
	4	22-Oct	23-Oct	04-Nov	16-Nov	14-Nov
Wedgetail (ungrazed)	1	15-Oct	20-Oct	02-Nov	03-Nov	12-Nov
	4	md[a]	md	md	02-Nov	09-Nov
Diamondbird	1	15-Oct	16-Oct	29-Oct	02-Nov	10-Nov
	4	18-Oct	15-Oct	29-Oct	03-Nov	09-Nov

[a] md = missing data

6 Apparent end of season wetting

From the data summary in Appendix C it can be seen that the soil appears to rewet at all depths after early December. At the shallow depths (0.2 and 0.4 m) this can be attributed, at least in part, to soil wetting as a result of late season rainfall. However at the deeper depths the apparent wetting is attributed to the temperature effect on the sensors, similar to that illustrated in Fig. B1 and described in Appendix B.

7 Summary and Conclusions

Despite the uncertainties introduced by temperature effects and not being able to measure at soil water potentials drier than 200 kPa, the data from the Watermark® soil water sensors allowed a number of useful observations to be made:

- the winter rain only penetrated to an average depth of 0.8 m across the plots
- there was evidence of strong soil water extraction by crop roots to at least 1 m, and some soil water extraction to 1.2 m, in all plots
- there were no strong treatment differences in the depth of wetting or depth of drying of the soil
- rate of soil drying, and therefore water use, by the grazed Wedgetail treatment was slower relative to the other treatments at and soon after the completion of grazing in August
- this slower water use in August/September had little effect on the total drying achieved by the grazed Wedgetail treatment, and it is inferred that there was little difference in total seasonal water use between the treatments
- this final conclusion may be affected by the dry seasonal conditions in which water use was controlled by soil water availability; in a wetter year, with excess available soil water, the results may be different

Appendix A. How the measurements were made

Overview

Measurements were made in each of six plots: the Wedgetail (grazed), Wedgetail (ungrazed) and Diamondbird treatments of each of Replicates 1 and 4 of the Marrar Grazing Wheat Trial. The measurement locations were about 1 m downslope of the centre of each plot. A schematic representation of the measurement methodology is shown in Figure A1.

At each measurement location Watermark® gypsum blocks were installed at 8 depths (0.2 m intervals from 0.2 to 1.6 m). They were installed in a single 50 mm diameter borehole; each sensor was packed in moist diatomaceous earth to ensure good contact with the soil, and the sensors were separated from each other by layers of bentonite.

Each set of 8 sensors was connected to a buried CSIRO Wireless micrologger located 1.5 m downslope from the sensors, the connecting cables being buried in a trench 0.4 m deep.

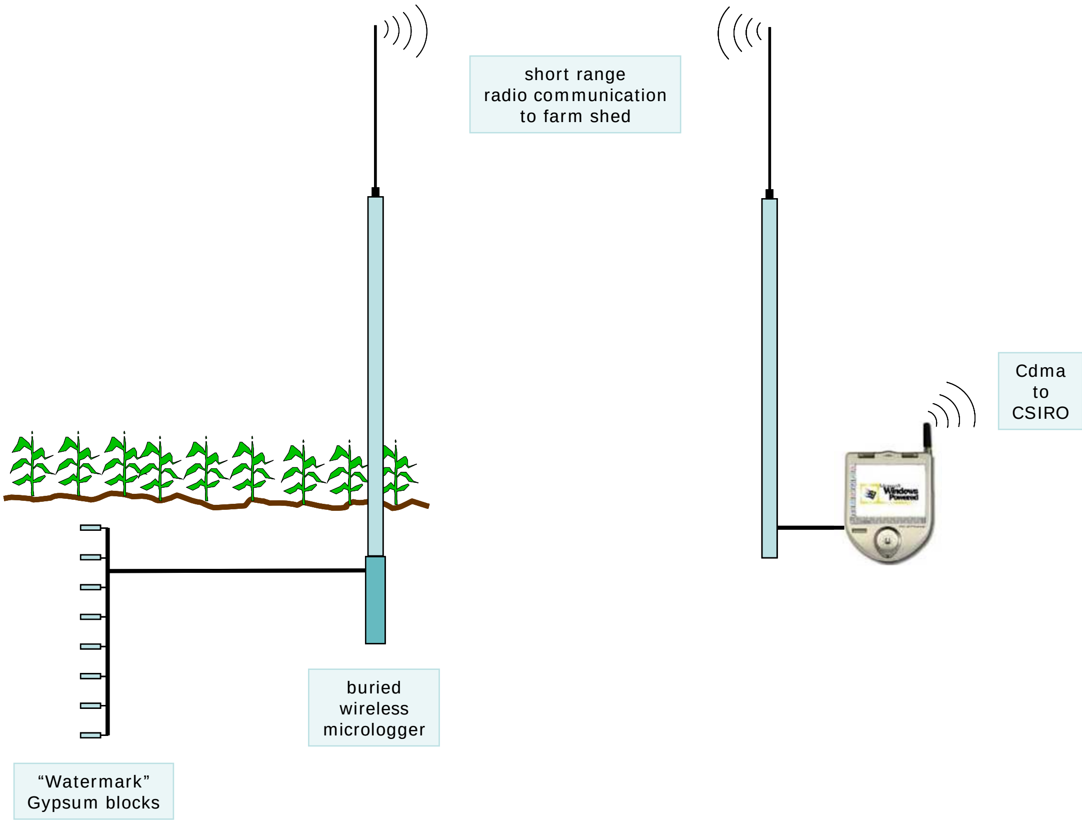


Figure A1 Overview of the measurement methodology.

At pre-programmed intervals (every 12 hours in this case), the microloggers read each sensor and radioed the results to a receiver located near the shearing shed a few hundred meters away. The receiver was connected to a small computer with a built-in cdma telephone. The computer stored the sensor results. Once each day it connected to the internet via the cdma telephone and sent the day's data file to a CSIRO computer. Before 7 am each day, the previous day's data was automatically added to an excel spreadsheet and graphs of the data were updated. These graphs were copied to another computer and displayed on the project website. All going well, the previous day's data were available for viewing after 7 am each day.

Occasional glitches occurred when the radio link failed because of excessive interference, or the cdma signal was not strong enough for the call to be made. Built-in fail-safe procedures keep these to a minimum and prevent data loss when it does happen. Provided the microloggers kept functioning, the data could also be recovered directly from their memories and patched into the dataset at a later date, as was done in several instances. Unfortunately some of the loggers failed at various times, and this accounts for the gaps that can be seen in the data, most noticeably on the ungrazed Wedgetail plots.

Watermark® gypsum blocks

The Watermark sensor was used for this project because it provides an inexpensive way to measure soil water status. It measures soil water potential rather than soil water content, which has advantages and disadvantages. Advantages include: inexpensive; easy to install; and provides an absolute measure of soil wetness or dryness. Disadvantages include: measurements cannot be directly related to soil water content or storage in mm; and the limit of accurate calibration is 200 kPa, whereas the theoretical lower limit for water extraction by crops is 1500 kPa.

The Watermark sensor is a type of gypsum block. These are porous blocks that wet and dry as the soil they are in contact with wets and dries. The water content of the block is measured by measuring its resistance. The gypsum in the block provides a buffer against background soil salinity so that it does not affect the resistance measurement.

The water content of the block does not equal the water content of the soil, but is related to the 'soil water potential' of the soil with which the block is in contact. Soil water potential provides an absolute measure of how wet or dry the soil is; a value of zero indicates that the soil is 'saturated', a value of ~10 kPa indicates that the soil is at 'field capacity' or 'drained upper limit', while a value of 1500 kPa indicates that the soil is at 'wilting point' - ie so dry that plants cannot extract more water from it. [In contrast the for a measurement of water content to be interpreted relative to the soil's upper and lower limits, the actual water contents at these limits needs to have been determined previously for the specific soil.]

Sensors such as the Watermark, which measure soil water potential, require less care to be taken during installation. They do not need to be in intimate contact with the soil, as is required for most sensors that measure water content. Instead, the sensor can be bedded in a contact material (usually diatomaceous earth) that ensures good contact between the sensor and the soil and allow it to equilibrate with the soil's water potential. In contrast, if a soil water content sensor is bedded in a contact material instead of being perfectly in contact with the soil, it measures the water content of the contact material instead of the water content of the soil.

For more information, see Appendix B: Interpreting the measurements.

Wireless microloggers

The Wireless micrologger has been custom-designed by CSIRO Land and Water. Each logger can measure up to 8 sensors. At a pre-programmed time (or times) each day, the logger automatically turns on, measures the sensors and stores the data. Every time measurements are made, the logger has the capability to radio the results to the receiver, as described below. Alternatively, to save power, results from several measurement times can be radioed together.

The micrologger has been designed to be buried and left unattended for long periods of time. It has a low power requirement, and its high capacity batteries will last several years at daily or sub-daily measurement intervals. The data are stored in memory (up to 5,000 individual measurements can be stored), so that if radio transmissions are interrupted, the data can be recovered by manually interrogating the logger with a PC.

Each logger is sealed in a watertight PVC housing and lowered down a PVC casing. While the casing extends to the soil surface, the top of the logger is at least 0.3 m below the soil surface. Thus, although the top of the casing may occasionally be damaged by, for example, tillage operations, the logger remains protected. However, to transmit the radio signal, an antenna needs to protrude above the soil surface. This is designed to be easily laid down on the soil surface to permit spraying operations and easily disconnected and re-connected at sowing and harvest.

Radio communication

The radio signal from the logger is transmitted through the antenna protruding 2 to 3 m above the soil surface, to a similar antenna connected to a receiver located at some distance away. This distance can be up to 5 km under ideal conditions, but the maximum practical range is more usually 2 to 3 km.

Telephone link

The radio receiver is connected to a pc-EPhone®, a combined cdma telephone and personal digital assistance running the Microsoft Windows CE operating system. Custom software running on the pc-EPhone receives and stores the measurements sent by the microloggers. At a pre-programmed time each day, the pc-EPhone connects to the internet and uploads the data to a CSIRO ftp site. Should a cdma connection not be able to be established, the data is kept in protected storage to be sent the next day. If the cdma link fails completely, the stored data can be downloaded to a PC or to a compact flash card.

Loading the data to the web page

Each morning, software running on a CSIRO server automatically copies any incoming data files from the ftp site, processes them, and adds them to an excel spreadsheet. This spreadsheet updates charts of the data and saves them as "gif" images, which are uploaded to the web page and are immediately available for viewing. While the quality of the charts is not extremely high, they are small files (< 15 kB) that can be downloaded quickly even on slow dial-up lines.

Appendix B. Interpreting the measurements

The measurements reported were made with Watermark® gypsum blocks, as described in Appendix A. Gypsum blocks measure soil water potential, not soil water content. The two are related, but not uniquely; the relationship is not linear (it is in fact close to logarithmic) and varies with soil type and from place to place within a given soil type as individual soil properties vary.

Unlike soil water content measurement, water potential measurements cannot, by themselves, indicate how much water is stored in the soil and available for crops. Soil water potential measurements are, however, much easier and cheaper to make that soil water content measurements and still provide much useful information.

Soil water potential provides an absolute measure of how wet or dry the soil is:

- a value of zero indicates that the soil is saturated - ie. water will ooze from the soil;
- a value of ~10 kPa indicates that the soil is at field capacity or drained upper limit - this is the practical upper limit of wetness; a well-drained soil, would rarely spend more than a day or two wetter than this
- a value of 1,500 kPa indicates that the soil is at wilting point - ie. so dry that plants cannot extract more water from it.

In contrast, a measurement of soil water content can only be interpreted in this way if the values of water content at these three limits (saturation, drained upper limit, and wilting point) are known in advance, which is usually not the case.

Temperature effects

A complication in interpreting measurements from gypsum blocks, and most other soil water sensors (including the very expensive ones), is that they are temperature dependent. Their output is affected not only by water content, but also by the soil temperature at the time of the measurement. Soil temperature changes in response to air temperature, although the magnitude of the change in soil temperature decreases with depth.

At shallow depths (less than about 200 mm), soil temperature reaches a peak in early afternoon and a low around dawn. Because of the time it takes for the soil to heat up and cool down, these daily variations are not seen below 200 mm, and so aren't a concern for the measurements reported here, the shallowest of which is at 200 mm. However, the seasonal oscillation in air temperature shows up at much greater depths, because in 6 months heat can travel down as far as 2 meters into the soil and cause a temperature rise. The seasonal oscillation of the Watermark gypsum block output caused by temperature is illustrated in Fig. B1.

The consequence of the temperature effect on gypsum block measurements is that some extra care is required when interpreting their output:

- in spring and summer, a gradual wetting in gypsum block output is more likely to be a result of increasing soil temperature than an increase in soil wetness
- in autumn and winter, a gradual drying in the gypsum block output is more likely to be a result of decreasing soil temperature than a decrease in soil wetness

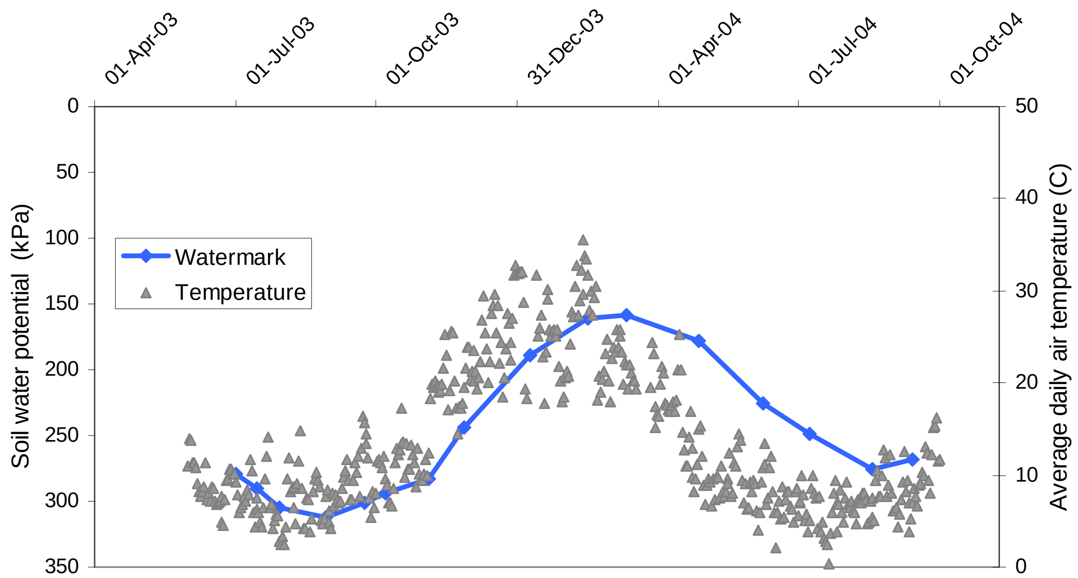
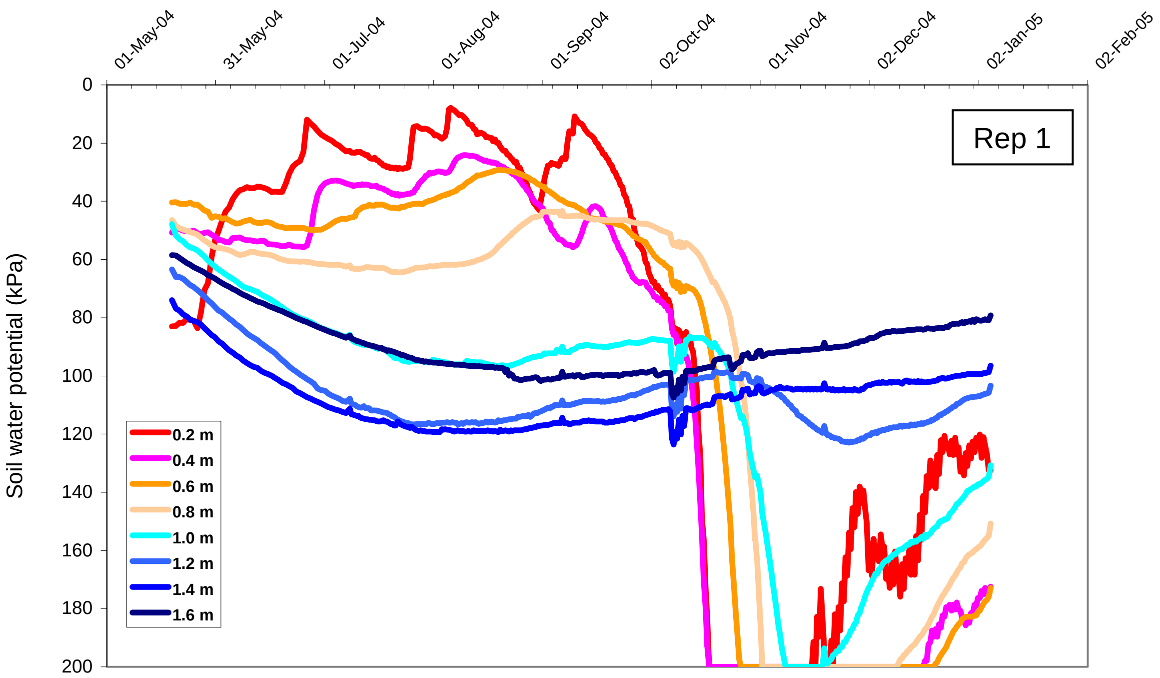
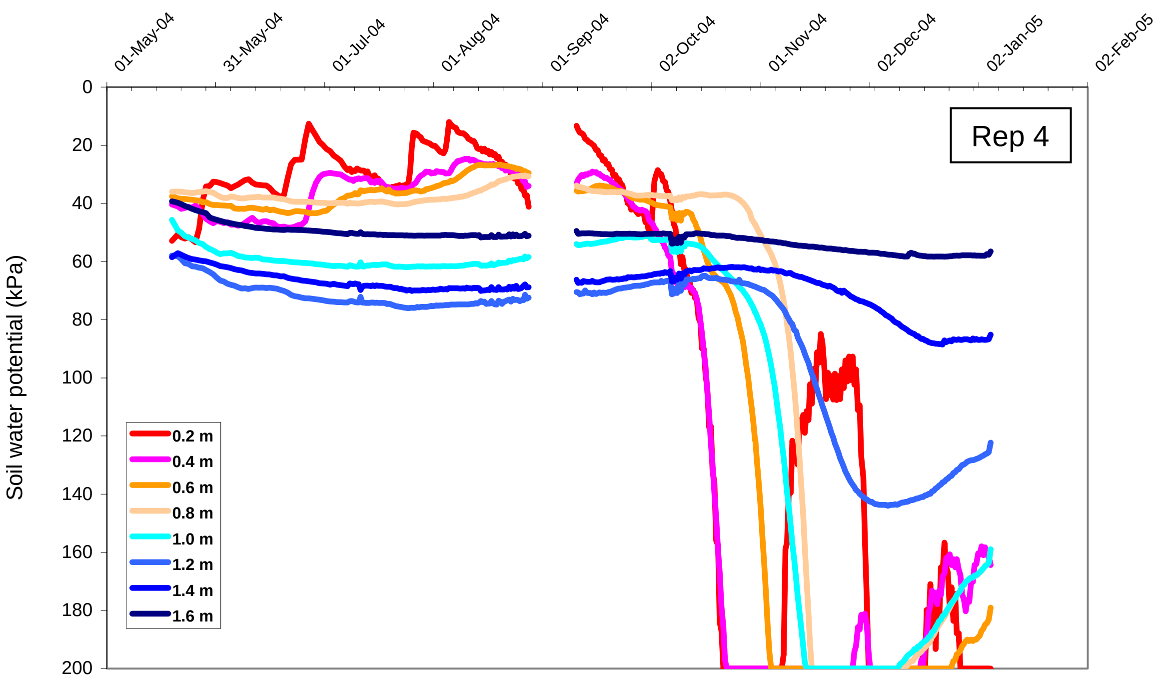


Figure B1 Soil water potential measured by a Watermark® gypsum block for a 12 month period at a depth of 1.7 m in a paddock at Charles Sturt University, Wagga Wagga. Independent measurements of soil water content with a neutron probe showed no variation during this period, because the soil had been previously dried by lucerne and there was insufficient rainfall to rewet it. The oscillation correlates with observed air temperature, subject to a lag of about 1 month.

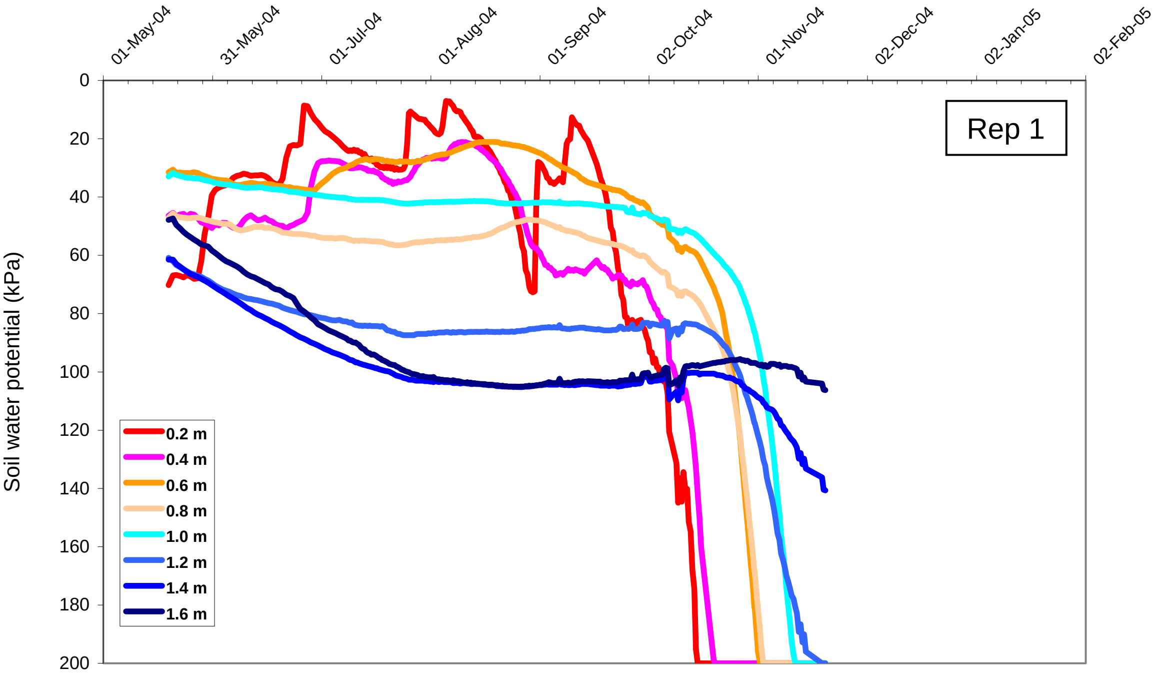
Appendix C. Data Summary

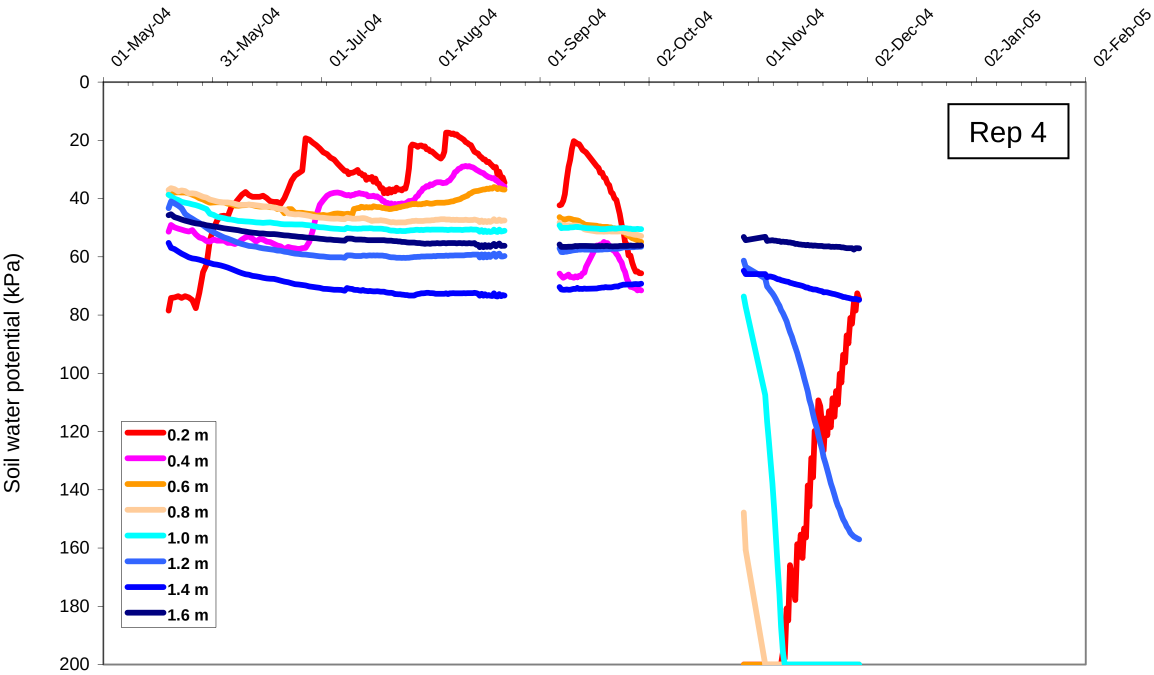
Wedgetail (grazed)





Wedgetail (ungrazed)





Diamondbird