Conservative water use by lucerne

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Abstract

Lucerne is widely used and promoted to ameliorate dryland salinity problems across a large proportion of the southern Australian mixed farming zone. To serve this purpose it must use its deep root system to extract subsoil water that has accumulated beneath a series of annual crops. Lucerne has a very high capacity to use water from the surface as shown by it's response to rainfall or irrigation, but less is known about it's ability to extract water from the deep subsoil. The soil environment of mature lucerne plants was manipulated to assess water extraction patterns from soil cores in a drainage lysimeter. A fresh watertable was established and maintained at 2.5 m depth; soil water contents were monitored with a neutron moisture meter and tensiometers, and roots were observed using minirhizotrons. Lucerne's dry matter response to a fresh watertable applied at 2.5 m was minimal. Results indicated that the rate at which lucerne will utilise water from depth for foliage growth was restricted by its genetic adaptations to surviving in a semi-arid environment. These adaptations will determine the upper limits of the extraction rate at which deeper drainage water can be retrieved by lucerne roots.

Key Words

salinity, subsoil water, lysimeter

Introduction

The replacement of native vegetation in the Murray Darling basin and the Western Australian wheat belt with annual crops and pastures has increased the water entering groundwater systems, raising watertables and increasing salinisation (1). It is believed that the incorporation of deep-rooted perennial species provides a feasible agricultural solution to this problem as perennial plants can extract water from greater depths than annual species (2) and may utilise water at times when annual species were not present. Lucerne (*Medicago sativa)* has the ability to extract water from deeper in the soil than annual crops and pastures, and most perennial pasture species, and thereby maintain a drier soil profile (3). The question is whether lucerne can use water from the subsoil as its primary source? If so, it may be ideally adapted to the management of dryland salinity. Conversely, if lucerne only has restricted use of subsoil water, and is only able to extract water at a rate sufficient for survival, it may be less well adapted for dryland salinity management. In this latter case the rate of extraction will depend on the physiological state of the plant, rather than the abundance of subsoil water.

To test the nature of the extractive function of the deep roots of lucerne, an experiment was set up in the drainage lysimeters at Charles Sturt University, Wagga Wagga. This investigation examined the relationship between the application of surface and subsoil water and above-ground dry matter production, to determine if lucerne would use subsoil water as it's primary water source for above-ground dry matter production.

Methods

Twelve intact cylindrical (250 cm long, 74 cm in diameter) monoliths each of two soil types were extracted during the summer of 1998-99. The two soils were a light clay kandosol, with 0-20 cm A, 20-55 cm B and 55+ cm C horizons, and a medium clay, high bulk density sodic (SAR >15%) vertisol, with 0-25 cm A and 25+ cm B horizons. The cores were enclosed in cylindrical steel casing and had a sand-filled base where water could be applied to form a watertable. Seed of two lucerne cultivars with contrasting winter dormancy's (winter-dormant Pioneer L34, and winter-active Pioneer L90) were inoculated and sown in May 1999. Minirhizotron tubes (740 mm long and 38 mm outside diameter), each scribed with lines in the

10 o'clock and 2 o'clock positions and scaled in 1 cm increments, had been fitted to all cores at 60, 85, 145 and 200 cm depths in January 2000. These tubes represented ~6% of the cross-sectional area of the cores. All cores were fitted with neutron moisture meter (NMM) access tubes using the kaolin slurry technique (4).

At the start of this experiment in January 2001, the plants were 20 months old. A watertable was imposed at 2.5 m depth in all cores. Tensiometers were installed horizontally at 210 cm, which was 40 cm above the imposed watertable. Readings from these tensiometers stabilised at water potentials of between -4and -10 kPa, indicating that soil water was readily available to roots at this depth.

When all plants in the cores were visibly water-stressed (day 0), half of them were surface watered (**+sw)** with 125 mm of simulated rainfall applied through a drip irrigation system over 48 hours. The remaining cores received no surface water (**-sw**). All cores were protected from summer rainfall by a clear polythene rain shelter fixed on a metal frame. NNM readings were taken weekly at nine depths in each core using a 16-second count. Root density was scanned along the 130 cm of scribed line in each tube with a bore scope and recorded by a mounted video camera. Functional roots that intersected the line were counted on a screen.

The total number of stems that had extended above the stubble in each core was counted every 5 days prior to and after watering. Shoot dry matter production was assessed by hand cutting to a height of ~3 cm at early flowering (day 29). Roots were first counted on day 4. Data were analysed as a factorial ANOVA.

Results

There was no statistical difference between the lucerne cultivars for each parameter (shoot number, shoot dry matter and root growth). As a result, the shoot number and dry matter data for each cultivar, but not the root growth data, were treated as replicates and these data re-analysed.

There was little evidence of increased shoot growth in the no surface water (**-sw**) treatments, where water was available from the 2.5 m deep watertable only. Shoot counts increased markedly where surface water was applied (**+sw**) in contrast to the **–sw** plants (Figure 1). By day 14 the growth response of the **+sw** plants was clearly established and shoot counts were discontinued.

The absence of a shoot growth response to water supplied to the base of the root system is shown in Figure 2. Dry matter production for the period showed very little response to the lower part of the root system being in moist subsoil whereas dry matter accumulated rapidly when the upper part of the root system was in moist soil. Dry matter production after 29 days by the **+sw** plants averaged 1.9 t/ha compared with an average of 0.09 t/ha from the **–sw** plants ($P<0.05$) (Figure 2). The plants growing in the kandosol producing significantly ($P< 0.05$) more dry matter in each treatment than those growing in the

vertisol (Figure 2).

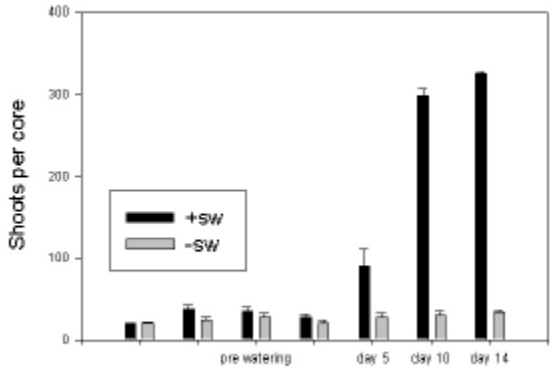

Figure 1 Shoot production per core.
Error bars = standard error.

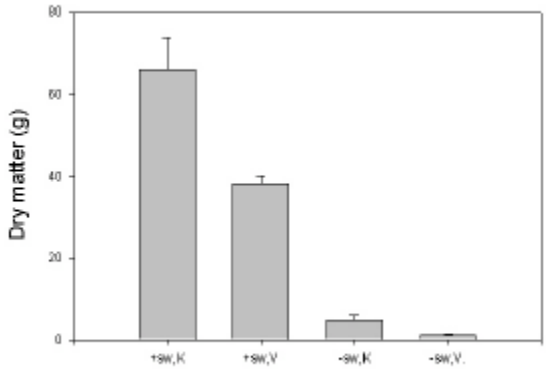

Figure 2 Dry matter production over 29 day period, grams per core.
Error bars = standard error.

Water extraction from the surface of the **+sw** treatment was rapid with a return to the initial soil water content after 30 days, whereas the profiles of the **–sw** remained static (Figure 3). When all of the applied water was taken up, the plants showed visible indications of water stress, and all treatments were harvested for dry matter.

The average number of root intersections over the 130 cm length of inscribed minirhizotron tube is shown in Table 1. No significant differences (P<0.05) were found between treatments at 200 cm depth, which is in the vicinity of the capillary fringe of the watertable. There were significantly (P<0.05) fewer roots at the 60cm depth in the surface watered cores than in the non-watered cores but this did not prevent the rapid extraction of water and accumulation of dry matter.

Table 1. Number of roots intersecting 130 cm of scribed line on bore scope tubes at four depths on 26 March 2001.

Depth (cm)	+sw90K	-sw90K	+sw34K	-sw34K	+sw34V	-sw34S	+sw90V	-sw90V	LSD[1] (P=0.05)
60	23	48	12	60	48	111	68	102	34
85	58	60	39	86	92	94	90	41	n.s.
145	105	0	4	89	200	103	134	117	n.s.
200	175	54	80	115	128	103	119	2	n.s.

+sw =surface watered, **-sw**=no surface water;
90=Pioneer L90 winter active lucerne, **34**=Pioneer L34 winter dormant lucerne;
K=Kandosol, **V**=Vertisol;
[1] LSD = least significant difference for ? surface water comparisons within each cultivar/soil type combination.

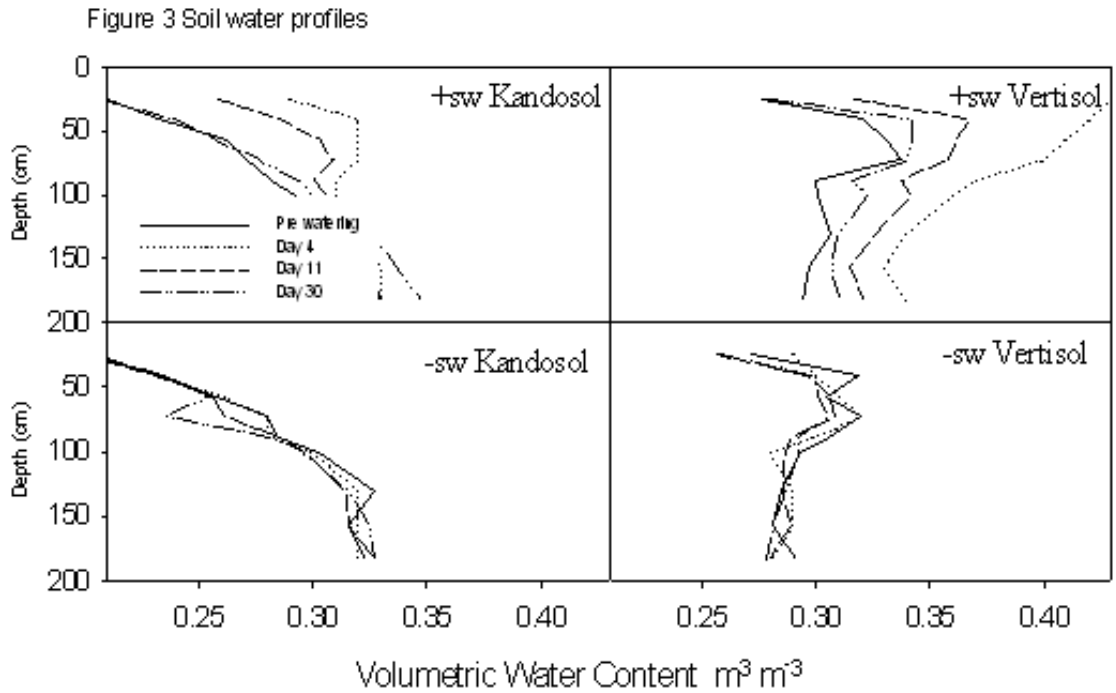

Figure 3. Volumetric water contents (m^3/m^3) to 200 cm depth of two soil profiles under lucerne prior to, and on three occasions after the application of 0 mm (-sw) and 125 mm (+sw) of simulated rain to the soil surface.

Discussion

Lucerne apparently produces foliage for extended periods after summer rain by drawing on subsoil water (5). These rates of foliage production are small compared with the potential of the plant, but very significant to the livestock industries they support (6). When foliage production is minimal during extended dry periods, it suggests that roots have extracted all the available soil water from their root zone and have not extended into moist subsoil or a watertable below, or that roots were unable to extend rapidly enough into moist subsoil to meet plant transpiration demands. When these limitations were addressed in this experiment, lucerne still produced very little dry matter, indicating that processes other than subsoil water availability were restricting water extraction. We conclude that despite being well watered at 2.5 m depth, the **–sw** plants failed to produce additional foliage because the upper layers of the soil profile were dry. This suggests that lucerne may be able to discriminate when the upper layers of the soil profile are dry and initiate processes to conserve water that is held deeper in the soil.

It is not uncommon for plants to restrict their water losses when the water content of the soil is decreasing. Hormones produced in roots growing in drying soil have been shown to regulate the plants' water losses independently of the water status of other roots (7). Abscisic acid is implicated in the increased extension of roots, and decreased shoot growth when plant roots occupy drying soil (8). Hormone signals from roots in drying soil would be expected to fade over time with the gradual physiological separation of the roots from the plants as water uptake ceased, or actual separation as the roots senesced. It is likely therefore that over time the plants would adapt to the supply of water at the base of the root system (at 2.5 m depth in our cores) as hormone signals from roots in the dry soil ceased to suppress shoot production. This was not observed in our experiment. Shoot production continued to be severely restricted in the *-sw* treatments throughout the experiment. It has been suggested (9) that the restriction in radial flow of water from the soil to the xylem may be a significant restriction, but why it should be different for deeper roots is not clear. The deeper roots may themselves be morphologically or functionally different in a way that we cannot identify at this time.

Our observations support the suggestion that lucerne evolved under arid or semi-arid conditions prior to domestication (10). The rapid breaking of dormancy and extraction of water by lucerne after rainfall that we see in temperate Australia is a common feature of desert plants. When water is available to desert plants they extract it rapidly and return to conservative growth when it is exhausted. It would be an evolutionary advantage for such plants to sense the dwindling supplies of surface water and have mechanisms to restrict growth and conserve subsoil water for survival. It appears that such mechanisms prevent the subsoil roots of lucerne from extracting water at high rates.

Conclusion

The hypothesis that lucerne would use subsoil water primarily for growth was not confirmed. When the principal source of water for lysimeter-grown lucerne was an abundant supply of fresh water at 2.5 m depth, the plant used this water conservatively and growth was limited. Survival mechanisms resulting from the plant's adaptation to a water-limited environment may to prevent the rapid extraction of subsoil water by lucerne. The upper limits to subsoil water extraction will be set by these survival mechanisms.

Acknowledgments

The authors wish to acknowledge the Grains Research and Development Corporation for funding this work and the Australian Research Council for funding the construction of the lysimeter.

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