A comparison of sainfoin cultivars and lucerne, with an emphasis on sainfoin responses to water stress

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Abstract

Sainfoin (*Onobrychis vicifolia* Scop.) is a non-bloating, drought resistant legume that mainly produces forage during early spring. The objectives of this study were to compare eight sainfoin cultivars with lucerne under non-limiting water conditions, and to examine the water stress responses of a single sainfoin cultivar in the field. Lucerne leaf area, leaf weight and stem weight were greater than for sainfoin cultivars. Significant differences between root, leaf and stem weight, and leaf area of sainfoin cultivars were observed.

In the field study, plant water status, relative water content and stomatal resistance were measured weekly at midday for the sainfoin cultivar Remont. There were significant differences between stomatal resistance and relative water content of stressed (rain-out shelter) and non-stressed (rain-fed control) plants. Water stress reduced LA to 25%, and total dry weight (leaf+stem) to 62%, of control plants. Relative water content of sainfoin was more sensitive to soil moisture than leaf water potential or stomatal resistance. The practical significance of the physiological and morphological responses of sainfoin to water stress is discussed.

Additional key words: *shoot/root ratio, stomatal resistance, specific leaf area.*

Introduction

Sainfoin (*Onobrychis vicifolia* Scop.) is a perennial legume with potential for forage production in dry conditions. It is not affected by alfalfa weevil (*Hypera postica* L.) (Hanna *et al.*, 1972; Diterline and Cooper 1975) and it does not cause bloat (Hanna *et al.*, 1972; McGraw and Marten 1986).

Sainfoin has been recognized as a possible alternative to lucerne (*Medicago sativa* L.) on the pumice soil of the Central Plateau of the North Island of New Zealand (Percival and MacQueen, 1980). Comparison of six sainfoin cultivars and lucerne in this area showed Melrose was the highest yielding sainfoin cultivar under an eight week cutting regime, but it only produced just over half the yield of lucerne (Percival and Cranshaw, 1986). In spring, sainfoin exhibits earlier growth than lucerne (Smoliake and Hanna, 1975).

Sainfoin has attributes which enable it to tolerate water stress. It has a deep rooting habit (Koch *et al.*, 1972) and has a high stomatal resistance (Rs) under water stress conditions, thus allowing it to maintain a higher relative water content (RWC) than lucerne during water stress (Mir Hosseini-Dehabadi *et al.*, 1993a). Bolger and Matches (1990) found a higher yield potential for sainfoin in spring than in summer, possibly indicating a higher water use efficiency in spring than summer.

We were interested in differences in the growth responses of sainfoin cultivars and lucerne in non-limited soil moisture and in the physiological mechanisms involved in the drought tolerance of sainfoin. The main objectives of this study were: a) to compare a range of sainfoin cultivars and lucerne in the absence of water stress, and b) to investigate the response of sainfoin to water stress in the field.

Materials and Methods

Glasshouse experiment

Seeds of six sainfoin cultivars (Grasslands G35, Remont, Cotswold-Common, Melrose, Eski, Pola), *O. tanaitica*, *O. transcaucasica*, and lucerne (Grasslands Oranga) were planted individually in pots (15 cm diameter and 18 cm height) on 26 December 1991, and subsequently thinned to 2 seedlings/pot on 2 January 1992. The media was 50% peat, 50% sand, and fertilizer (Osmocote+® 14-6-12, 2.25 g/l; superphosphate 0-9-0-11, 1.5 g/l; lime 1.5 g/l; dolomite 3.0 g/l; Micromix® 0.6 g/l). Plants were grown in a glasshouse at Palmerston North with natural daylight and day/night temperature

25/15°C. Pot moisture was maintained at 'field' capacity by top-watering automatically up to four times daily. At harvest (1 March 1992), leaves were separated from stems and leaf area (LA) measured with a planimeter (Li-Cor Inc, model 3100). Leaf (LW) and stem (SW) dry weight were determined after drying at 80°C for 72 h. Soil was washed from roots and root weight (RW) determined after 72 h at 80°C. A randomized complete block design with four replicates was used.

Field experiment

The sainfoin cultivar Remont was used to study water stress effects in the field. Seed was germinated in "peat pots" in the glasshouse (25 October 1992) and seedlings transferred to the field (1 November). The soil was a Tokomaru silt loam (Fragiaqualf, gleyed yellow-grey earth). There were two adjacent experiments (rain-fed control and water stressed) each comprised of three replicates. Between 3 November 1992 and 2 March 1993 a fully automatic rain-out shelter moved to cover the stressed experiment within 30 s of the onset of rain. A plastic sheet was buried to 1 m to prevent lateral flow of soil water into the stressed experiment.

Volumetric soil moisture content (VSWC) (cm^3/cm^3, %) of the control and stressed experiments was measured weekly in the zones 0-15, and 50-70 depth. A time domain reflectometer (TDR) measured the surface VSWC with a single pair of vertical 15 cm probes per pot. The deeper VSWC was calculated from the difference between TDR readings of the probes at 70 and 50 cm depth. Approximately weekly measurements were made of a) petiole water potential (LWP) by pressure bomb (Plant Water Console, model 3000) (8 times, 22 December - 2 March) and b) stomatal resistance (Rs) using a poromoter (Delta) (5 times, 20 December - 2 March), on two fully expanded leaves at midday from near the top of the canopy. Each week (6 times, 22 December - 2 March) ten leaf disks were cut at midday, weighed immediately (FW), soaked in distilled water for 4 h, blotted to surface dryness by paper towel, re-weighed (TW), dried 24 h at 80°C, re-weighed (DW) and relative water content (RWC) calculated as (FW - DW)/(TW - DW)%. Plants were harvested on 3 March 1993 and LA, LW and SW determined as for the glasshouse experiment.

The means for LA, SW, LW, and SLA from the water stressed and the control experiments were compared by t-test. Physiological data from the control and the stressed experiments were combined to derive a single relationship with VSWC. Equations were chosen which gave high R^2, using the FITLS option of the GLE program (C. Pugmire , Industrial Research, pers. comm.).

Results

Glasshouse experiment

The LW and SW for lucerne was significantly greater than for all sainfoins (Table 1) ($P<0.05$). For both LW and SW Eski, Melrose, and Remont were significantly greater than Cotswold-Common. There was no significant difference between RW of lucerne and the sainfoins. There was no significant difference in the specific leaf area (SLA) with the result that the relative differences in LA were similar to LW.

Field experiment

Initial VSWC was similar for both the control and stressed experiments. Subsequently, topsoil moisture (0-15 cm depth) decreased for the water stressed experiment but did not change appreciably at 50-70 cm depth (Fig. 1). The VSWC of the control experiment was always close to field capacity.

Significant differences were found between LA ($P<0.05$), LW ($P<0.01$) and SLA ($P<0.05$) of the stressed and non-stressed Remont (Table 2). Non-stressed plants had a higher LA and LW, but smaller SLA than the stressed plants (Table 2).

Significant differences in the midday LWP between the water stressed and non-stressed plants were only found at the last two observations, when VSWC was less than 15%. Variation in LWP was related to VSWC by an exponential equation that showed rapid change (decrease) in LWP below 19% VSWC (Fig. 2).

Measurement of the RWC of stressed plants began when the top soil VSWC (0-15 cm) in the stressed experiment was less than 25%. The RWC of water stressed Remont was significantly lower than that of non-stressed Remont, at all observations. A cubic function relating RWC to VSWC (including stressed and control plants) accounted for 93% of the variation in RWC and showed appreciably lower RWC when the VSWC was less than 32%. RWC was unchanged between 32-46% VSWC (Fig. 2).

Initial observations of the adaxial and abaxial Rs of leaves at stressed and non-stressed Remont were similar, but Rs was significantly greater for stressed plants once VSWC was less than 21%. Exponential equations relating the adaxial and the abaxial Rs to VSWC showed a rapid increase in Rs when VSWC was less than 20% (Fig. 2).

Table 1. Leaf area (LA), leaf dry weight (LW), stem dry weight (SW), root dry weight (RW), and specific leaf area (SLA) of eight glasshouse-grown sainfoin cultivars and species, and lucerne, at 65 days after planting.

Cultivar	LA (cm^2/plant)	LW (g/plant)	SW (g/plant)	RW (g/plant)	SLA (cm^2/g)
Lucerne (Oranga)	1484 a	8.79 a	10.91 a	5.24 a	172.4 a
Grasslands G35	1220 ab	5.10 bc	5.43 bc	4.27 a	236.6 a
Eski	1143 abc	6.21 ab	5.58 b	5.30 a	188.5 a
Melrose	1003 abc	5.89 bc	5.52 b	3.87 a	170.5 a
Pola	947 abc	5.75 bc	4.42 bc	4.17 a	165.3 a
O. tanaitica	815 bc	4.73 bc	4.61 bc	3.97 a	176.4 a
O. transcaucasica	741 bc	4.18 bc	4.82 bc	4.16 a	176.2 a
Remont	669 c	4.41 bc	6.41 b	4.64 a	150.3 a
Cotswold Common	615 c	3.29 c	2.01 c	2.04 a	188.2 a
Significance	0.05	0.028	0.003	0.528	0.192
S.E.M.	188.7	0.96	1.15	0.97	19.28

Numbers are the mean of four replicates,
Within a column, numbers with the same letter are not significantly different.

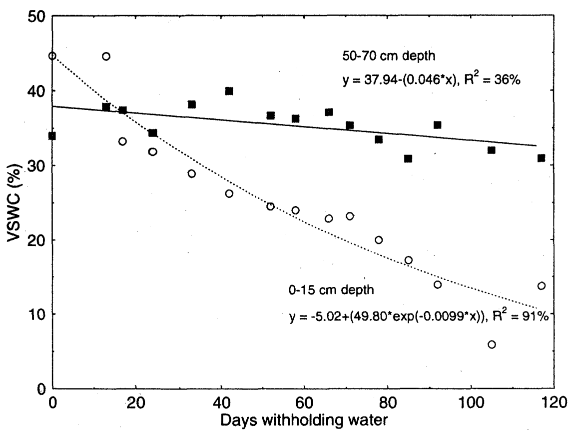

Figure 1. Volumetric soil water content (VSWC, cm^3/cm^3 %) for 0-15, and 50-70 cm depth under a rain-out shelter. Symbols are means of three replicates.

Table 2. Leaf area (LA), leaf dry weight (LW), stem dry weight (SW), and specific leaf area (SLA) of field grown Remont, for stressed (rain-out shelter) and non-stressed (rain-fed control) treatments.

Treatment	LA (cm^2/plant)	SW (g/plant)	LW (g/plant)	SLA (cm^2/g)
Stressed	1037.5	26.81	16.66	62.27
Control	4237.9	29.72	40.06	105.78
T-Test	$p<0.01$	ns	$p<0.01$	$p<0.05$

Numbers are the mean of three replicates

Discussion

Glasshouse experiment

Lucerne was more productive than sainfoin, with higher leaf area, leaf weight, and stem dry weight, in agreement with the results of Sheehy and Popple (1981). The overall mean LA and above-ground dry matter of sainfoin was 895 cm^2/plant, and 9.8 g/plant, respectively, whereas LA and above-ground dry matter for lucerne was 1484 cm^2/plant and 19.7 g/plant, respectively. This faster growth of lucerne compared to sainfoin was also reflected in its development. Lucerne reached the bud stage approximately a week earlier than most sainfoin cultivars.

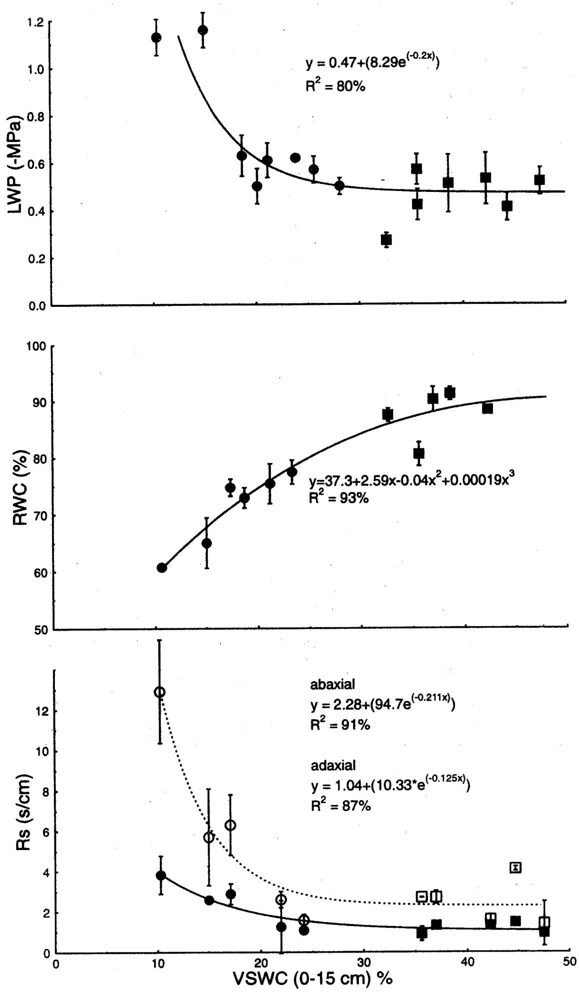

Figure 2. Relationships between Remont petiole water potential (LWP, -MPa), relative water content (RWC, %), or stomatal resistance (adaxial surface, closed symbols; abaxial surface, open symbols) and volumetric soil water content (0-15 cm, VSWC, cm^3/cm^3 %), for rain-fed (nonstressed) plots (□,■) and stressed plots (O,●). Symbols are means of three replicates. Vertical bars show ±standard error of the mean.

Among the sainfoin cultivars, Remont and Cotswold-Common had the lowest LA (Table 1). Reasons for this, however, were probably different for the two cultivars. Remont is representative of "two-cut" sainfoin types which show earlier growth and maturity than "one cut" types (Carleton and Delaney, 1972). The low yield of Cotswold-Common was in agreement with Rumball (1982) who found Cotswold-Common was less productive than Pola, Remont, and Melrose. The lower LA of Remont may have resulted from senescence, since it matured sooner than the other sainfoin cultivars and lost leaves prior to harvest. In the case of Cotswold-Common, the low LA was probably due to slower growth. This cultivar did not flower during the experiment. The rapid growth of Remont might be a useful attribute for escaping drought, when soil moisture is limited for growth late in the growing season.

Root dry weight of sainfoin cultivars and lucerne was similar, in contrast to the results of Mir Hosseini-Dehabadi *et al.* (1993a) who showed that the root dry matter of sainfoin was greater than for lucerne. These contrasting results were probably due to a smaller pot size in this study. The shoot/root ratio of sainfoin cultivars was 2.39 and that of lucerne was 3.78. The greater relative allocation of carbohydrate to roots by sainfoin suggested that root size was a character that might aid survival of sainfoin under dry conditions.

The leaf area/plant weight ratio (LAR) of sainfoin (91.2 cm^2/g) was higher than for lucerne (75.3 cm^2/g). This greater leafiness of sainfoin shoots relative to lucerne shoots resulted from a lower stem dry weight of sainfoin. The SLA of sainfoin cultivars (mean 181 cm^2/g) and lucerne (172 cm^2/g) were similar. In contrast, Sheehy and Popple (1981) found in a field experiment that the SLA of sainfoin was half that of lucerne. A possible explanation for this difference was the different environmental conditions of the field and glasshouse; for example, air temperature, relative humidity, and light intensity in the field were not as constant as in the glasshouse. In our field experiment the SLA of Remont was 43% of its SLA in the glasshouse.

Field Experiment

Leaf area and yield of Remont decreased as VSWC decreased (Table 2). Leaf dry matter, LA, and stem dry matter decreased 58, 10, and 76% under water stress but SLA increased 47% in control plants. The greater decrease in LA was probably due to decreased RWC when VSWC was less than 32%. Low RWC would impair cell elongation (Begg and Turner, 1976).

Relative water content of the stressed plants was significantly less than that of the control plants earlier than for LWP or Rs. LWP was less sensitive to water stress than RWC and Rs which suggested that maybe osmotic adjustment occurred in the water stressed sainfoin leaves (Begg and Turner, 1976).

Stomatal resistance Rs of the adaxial leaf surface (2.2 s/cm) for sainfoin was lower than for the abaxial (8.1 s/cm) leaf surface which was in contrast to the expected response. Stomatal resistance for the adaxial and abaxial leaf surfaces of lucerne, for example, are equal (Carter *et al.*, 1982; Mir Hosseini-Dehabadi *et al.*, 1993b). The adaptive significance of the relatively lower adaxial Rs of sainfoin was not apparent, though possibly leaflet folding under water stress would result in lower transpiration loss due to high humidity on the adaxial surface.

Conclusion

Lucerne out-yielded all sainfoins under non-limiting soil moisture conditions. Nevertheless, sainfoin exhibited a greater relative leafiness and a lower shoot/root ratio than lucerne. Costwold-Common yielded less than all other sainfoins. Remont grew faster than the other sainfoins and matured sooner. A relatively large root system (high root/shoot ratio) is a possible mechanism that could assist sainfoin survival under water stress. Relative water content appeared to be more sensitive to water stress than leaf water potential and stomatal resistance and possibly osmotic adjustment occurs in sainfoin. The stomatal resistance of the abaxial surface of sainfoin leaves was higher than that of the adaxial surface in stressed and non-stressed conditions, but any adaptive significance of this difference was not apparent.

Acknowledgements

Thanks are extended to Ministry of Jahad Sazandegi, Iran, for PhD support, Terry Lynch for assistance with field work, Mark Osborne for rain-out shelter maintenance, Ray Johnstone for greenhouse management, and the Margot Forde Germplasm Centre - AgResearch and Montana State Univ., USA, for the provision of seed.

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