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ABSTRACT

Legume management under irrigation in semiarid regions can be difficult due to a broad spectrum of edaphic factors. Ground cover and dry matter yield of alfalfa (*Medicago sativa* L.), birdsfoot trefoil (*Lotus corniculatus* L.), cicer milkvetch (*Astragalus cicer* L.), crownvetch (*Coronilla varia* L.), kura clover (*Trifolium ambiguum* M.B.), red clover (*T. pratense* L.), sainfoin (*Onobrychis viciifolia* Scop.), strawberry clover (*T. fragiferum* L.), and white clover (*T. repens* L.) were compared under hay management from 1999 to 2001 at Tucumcari, N.M., in a strip-split plot experiment over time. Soil moisture treatments were: furrow-irrigation once for each of six harvests (*typical irrigation*); that plus irrigated monthly November through March (*winter irrigation*); and infrequent irrigation of poorly drained soil (*poorly drained soil*). There were four replications within each soil moisture treatment. Year x soil moisture treatment x species interactions existed for ground cover and annual dry matter yield. Annual yields of birdsfoot trefoil, kura clover, strawberry clover, and white clover were <4 Mg ha⁻¹. Annual yields increased over time under typical irrigation for alfalfa (8.5 to 15.8 Mg ha⁻¹), cicer milkvetch (3.7 to 7.3 Mg ha⁻¹), and crownvetch (2.7 to 6.5 Mg ha⁻¹), while they declined for red clover (3.6 to 1.7 Mg ha⁻¹) and sainfoin (3.0 to 0.3 Mg ha⁻¹). Winter irrigation increased first-harvest yields of all species except birdsfoot trefoil. Although lower yielding, cicer milkvetch, crownvetch, and red clover are alternatives to alfalfa in low-maintenance systems.

INTRODUCTION

While it is anticipated that few species will be better adapted to a region than those already commonly grown (Beuselinck et al., 1994; Rogers et al., 1997b), continued screening is needed to identify the potential of species in previously untested environments (Rogers et al., 1997b). Marginal areas and reclamation sites that should be established in permanent cover are of notable concern. If species adapted to marginal lands can be grazed as pasture or harvested as hay, an economic benefit in addition to soil stabilization benefits can be derived. Once climatic adaptation is determined, several factors must be taken into account when selecting species for marginal areas (Clark, 2001). In semiarid regions, high pH, saline (Rogers et al., 1997b) and/or sodic conditions, and soil moisture availability must be considered even under irrigation (Tapia and Lugg, 1986). Poor drainage often is exacerbated by saline and/or sodic conditions caused by a calcareous substratum (Brady, 1974; Ross and Pease, 1974).

Grasses are generally more tolerant of some stresses than legumes (Rogers et al., 1997b); however, legumes are usually more productive and higher in nutritive value than grasses, with the added benefit that nitrogen fixation by the legume also promotes growth of the associated grass in mixed pastures (Beuselinck et al., 1994; Guldan et al., 2000; Lauriault et al., 2003). While there might be only one or two legume species capable of maximizing production on a given site (Beuselinck et al., 1994), there might be several species capable of providing satisfactory production or other benefits across a variety of soil conditions in an otherwise stable climatic environment (Casler and Walgenbach, 1990; Clark, 2001).

Like many plant groups, legumes can be classified into two major categories based on whether or not they can reproduce vegetatively. Clone-formers, which spread vegetatively by rhizomes or stolons, are usually better adapted than crown-formers to unstable environments

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because they expand into areas of less competition (Beuselinck et al., 1994). Surviving periods of environmental stress by inhabiting areas of low stress and investing in vegetative reproductive structures allows these species to recolonize unoccupied areas once the stress is removed (Beuselinck et al., 1994). Crown-formers, which do not spread vegetatively, are most effective in stable environments because they can compete for limited resources (Beuselinck et al., 1994).

Alfalfa, a crown-former, has long been accepted as the most broadly adapted perennial cool-season forage legume in the world (Martin et al., 1976) and is widely used in hay and pasture systems in the Southern High Plains of the U.S. It is not, however, without limitations—alfalfa can cause bloat in animals (Berg, 1990; Bolger and Matches, 1990; Lauriault et al., 2005a) and can be vulnerable to insect pests (Berg, 1990; Bolger and Matches, 1990). Additionally, even though individual plants can be long-lived (Rumbaugh and Pedersen, 1979), in the absence of a rotation interval allelopathy inhibits long-term stand persistence through plant replacement (Beuselinck et al., 1994; Hegde and Miller, 1990).

Some research has been conducted to find alternatives to alfalfa for use in hay and pasture systems in the region (Berg, 1990; Bolger and Matches, 1990). Other forage legumes that have been compared to alfalfa also have limitations, such as low initial stand density or slow stand development that leads to low yields early in the stand life (Guldan et al., 2000). Some forage legume species have not yet been explored in the Southern High Plains. Additionally, testing has not been adequately conducted under a variety of soil moisture conditions that would demonstrate broad adaptation within the region where irrigation with surface water is often possible from April through October.

The objective of this research was to measure changes over time in stands of selected perennial cool-season forage legumes under different soil moisture situations typical of irrigated pastures and hayfields in the Southern High Plains of the U.S., and to measure dry matter (DM) yield of established stands.

MATERIALS AND METHODS

Studies were conducted from 1997 to 2001 at the New Mexico State University Agricultural Science Center at Tucumcari, N.M. (35.20° N, 103.68° W; elev. 1247 m), comparing the same species of perennial cool-season forage legumes under three different soil moisture treatments. There were four randomized complete blocks nested within each soil moisture treatment. The soil moisture treatments were as follows.

- (1) **Typical irrigation.** Furrow-irrigation once before each of six harvests taken May through late October, when surface water was available.
- (2) **Winter irrigation.** Same as typical irrigation, but also irrigated monthly after the final harvest, November to March, using ground water.
- (3) **Poorly drained soil.** Poorly drained soil irrigated only as needed to maintain a moist soil surface, but generally less than once per harvest.

The typical and winter irrigation tests were planted in an area with soils of mixed Canez fine sandy loam (Fine-loamy, mixed, thermic Ustollic Haplargid) and Quay fine sandy loam (Fine-silty, mixed, superactive, thermic Ustic Haplocalcids) with initial soil test levels of 48 mg kg⁻¹ P (NaHCO³ extractant), 192 mg kg⁻¹ K (ammonium acetate extractant), 8.2 pH, 0.04 dS m⁻¹ soluble salts, and 0.9% Na base saturation. The rooting zone in these soils is approximately 1.5 m, and water-holding capacity is 0.18 cm cm⁻¹ (Ross and Pease, 1974). The poorly drained soil was Canez fine sandy loam, calcareous variant, which had soil test levels of 34 mg kg⁻¹ P (NaHCO³ extractant), 236 mg kg⁻¹ K (ammonium acetate extractant), 8.2 pH, 0.24 dS m⁻¹ soluble salts, and 15.4% Na base saturation, making it borderline saline/sodic (Brady, 1974; Lauriault, unpublished data, 1997). The soil had a sandy clay loam substratum with high lime content (Ross and Pease, 1974) and the water table was approximately 1 m below the surface (Lauriault, unpublished data, 1998). The poorly drained site was downslope from other irrigated land and an earthen irrigation canal and was usually kept wet by subsurface drainage from those areas. A drainage ditch constructed around the area was used when necessary to allow sufficient soil drying to support harvesting equipment.

Nine species of perennial cool-season legumes were tested, including seven varieties of alfalfa ('ABT 405', 'Alfagrade', 'AmeriGraze 401+Z', common (variety unstated from South Dakota), 'OK49', 'Salado', and 'Supercuts'), birdsfoot trefoil (a locally available blend of 'GA-1' and 'Dawn' sown together), 'Monarch' cicer milkvetch, 'Chemung' crownvetch, 'Rhizo' kura clover, 'Kenstar' red clover, 'Renumex' sainfoin, strawberry clover (variety not stated), and 'Advantage' white clover. The seeding rate was 22.5 kg ha⁻¹ for alfalfa, crownvetch, kura clover, and strawberry clover and 9.0, 6.7, 39.3, 19.0, and 2.4 kg ha⁻¹ for cicer milkvetch, birdsfoot trefoil, sainfoin, red clover, and white clover, respectively. Seed of each species was inoculated with the appropriate strain of *Rhizobium*.

Seedbeds were conventionally tilled and formed into beds on 0.9 m centers for furrow irrigation. Plots 4.6 m

Table 1. Monthly total precipitation at Tucumcari, New Mexico, from 1997 to 2001 and the long-term (1905–2002) means.

Year	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sep.	Oct.	Annual
Total precipitation, mm													
1997–1998	14.2	68.6	0.8	15.5	65.8	31.2	2.0	3.6	62.2	121.2	15.5	116.8	517.4
1998–1999	10.7	4.3	42.7	0.0	31.8	45.5	148.1	43.9	14.0	59.4	50.3	16.5	467.2
1999–2000	1.3	20.8	0.3	0.0	44.5	18.8	21.6	29.7	57.2	6.6	1.8	97.3	299.9
2000–2001	10.9	21.3	17.0	24.1	67.3	2.5	71.6	44.7	17.0	71.9	4.8	3.8	356.9
Long-term mean	18.3	16.3	9.9	12.7	19.1	29.2	51.1	48.3	66.8	68.3	38.4	33.5	411.9

Table 2. Monthly mean air temperatures at Tucumcari, New Mexico, from 1997 to 2001 and the long-term (1905–2002) means.

Year	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sep.	Oct.	Annual
Mean temperature, °C													
1997–1998	7.2	1.7	5.6	6.1	7.8	12.2	20.6	25.0	27.2	24.4	23.9	16.7	14.9
1998–1999	10.6	5.0	6.7	9.4	10.0	13.3	23.9	23.3	26.7	26.1	21.1	15.6	16.0
1999–2000	12.2	5.0	6.7	9.4	10.6	16.1	22.2	24.4	27.8	29.3	23.9	15.0	16.9
2000–2001	5.0	2.2	1.7	6.7	8.3	17.2	18.9	25.0	28.9	26.1	22.8	16.1	14.9
Long-term mean	8.3	3.3	3.3	5.6	9.4	13.9	18.9	23.9	26.1	25.0	21.1	15.0	14.5

x 1.8 m were sown on 18 and 19 September 1997 using a disk drill (20-cm drill spacing) fitted with a seed-metering cone. During the four days after planting, 28.7 mm of precipitation fell, which promoted germination. All plots were irrigated on 3 October 1997, after which precipitation events occurred approximately every 2 wk until mid-November, keeping the surface 5 cm moist and helping to overcome a common problem of establishing smaller-seeded species such as perennial forage legumes on sandy soils (Keeling et al., 1996; Rehm et al., 1998). Irrigation water was delivered through gated pipe and for sufficient duration to completely wet the center of the beds for their full length. Surface water was available from 26 April until 26 October 1998, 19 April through 30 October 1999, 26 April through 20 October 2000, and 24 April through 20 October 2001. Historical irrigation flow rate data at this location, collected as described by Ziska et al. (1985), was used to estimate that approximately 20 cm of water was applied with each irrigation. It is not likely that all of the applied water infiltrated the soil, because furrow irrigation efficiency can be as low as 50% (Rogers et al., 1997a). Additionally, it is likely that some deep percolation occurred, at least partially accumulating in the poorly drained site. Experimentation was discontinued after the 2001 growing season because irrigation water was unavailable due to drought in the watershed.

No preplant fertilizers were applied. Each year beginning in 1999, before the initiation of growth, 25 kg ha⁻¹ N and 117 kg ha⁻¹ P, were broadcast on each soil mois-

ture treatment area using 11-52-00, which was the only available P source. Alfalfa weevil (*Hypera postica* Gyll.) was not a problem in the area during test years. However, cowpea aphid (*Aphis craccivora*) did infest nearby fields in 2001, so all plots were protected with 584 ml ha⁻¹ permethrin (38.4% a.i.) on 3 April, when nearby fields were treated.

In April 1998, initial stand density was visually estimated as a percentage of drilled row occupied by established plants. Percentage ground cover of all sown species was visually rated in April 1999 to 2001. These ratings, based on a whole plot estimate, were made by the same observer each year. Standing forage was not removed until 28 May 1998 to permit observation of date of first flower and plant height. Other harvest dates in 1998 were 20 June, 13 August, and 6 November.

From 1999 to 2001, DM yields were measured in May, June, July, August, and September, when the alfalfa was bud to 10% bloom, and in late October/early November, approximately 7 d before the average killing frost. For each harvest, topgrowth 7.5 cm above the bed tops was collected using a self-propelled forage plot harvester equipped with a reciprocating blade and electronic scales. Fresh weights were measured in the field. When weed infestations were high, larger weeds were removed prior to recording the fresh weight, and proportional contribution by remaining weeds was estimated and used to adjust fresh weights to reflect weed-free forage (Sheaffer and Marten, 1991). Immediately after weighing each plot, a sample of up to 400 g was

collected and placed in a paper bag and sealed inside a plastic bag. Samples were weighed and plastic bags removed before drying for 48 h at 70°C. Samples were then reweighed to determine DM concentration, which was used to convert fresh harvest weights to DM yield.

Weather data were collected from a National Weather Service station located within 1 km of the study area (Tables 1 & 2). The climate in the region is continental, characterized by cool, dry winters and warm, moist summers (Kirksey et al., 2003). Approximately 83% of the precipitation occurs as intermittent, relatively intense rainfall events from April through October. July and August typically have the highest precipitation (Kirksey et al., 2003). Above-average precipitation fell from November 1997 to October 1998 and in 1998–1999, but 1999–2000 and 2000–2001 were well below average (Table 1). All four stand years were warmer than average, mostly because of higher winter temperatures (Table 2).

The test was analyzed as a strip-split plot repeated across years and harvests (Littell et al., 1996) with soil moisture treatment as the strip plot, species as the subplot, and cultivar within species as the sub-subplots. Replicates were nested within soil moisture treatments. Percentage initial stand density, ground cover, and harvest and annual DM yield were subjected to SAS PROC MIXED ANOVA to test the main effects of soil moisture treatment, species, cultivar within species, year, and harvest and all possible interactions (SAS Inst., 2001). The PROC MIXED procedure allocated all degrees of freedom and associated variance for cultivar within species within alfalfa. Rep x soil moisture treatment, rep x soil moisture treatment x species, rep x soil moisture treatment x cultivar within species, rep x soil moisture treatment x species x harvest, rep x soil moisture treatment x cultivar within species x harvest, and residual mean squares were considered random and used as denominators for tests of significance (Littell et al., 1996). All reported differences, including significant interactions, are significant at $P \leq 0.05$. When an interaction was significant, the analysis was sliced by species and protected least significant differences were used to determine where differences occurred between soil moisture treatments within years or harvests and between years or harvests within soil moisture treatments for each species. Differences between cultivar within species were few and limited to alfalfa, were small in magnitude compared to species differences, and will not be discussed (Guldan et al., 2000; Lauriault et al., 2003, 2005b).

RESULTS AND DISCUSSION

Concern has been expressed that soil moisture status and salinity/sodicity levels in the poorly drained soil

used in this study are “hopelessly confounded.” This is acknowledged; however, as the co-occurrence of poor drainage and saline/sodic conditions is common in this region, inclusion of the combination as a treatment effect is justified and the confounding does not negate the response by these various species under the conditions in which they were tested. Additionally, inclusion or omission of the poorly drained treatment has no effect on observed differences between the typical and winter irrigation treatments.

The objective of the study was to determine legume performance under conditions typical to the Southern High Plains, which include poorly drained saline/sodic soils, rather than to establish whether it was poor drainage or salinity/sodicity that affected legume performance. It will be left to others to determine by scientific method whether the response was related to soil moisture, to saline/sodic conditions, or to the combination. Still, this section includes discussion of soil moisture and/or saline/sodic conditions as the possible cause of the treatment response.

Ground cover. No interaction existed between soil moisture treatment and species for initial stand density. Differences existed between soil moisture treatments (62%, 72%, and 75% for the poorly drained soil and the typical and winter irrigation treatments, respectively, $LSD = 6$). Adequate precipitation during the fall after seeding ensured uniform establishment before winter. Continued irrigation during winter did not give significant improvement in plant establishment from seed for that treatment compared to typical irrigation. Borderline saline/sodic conditions in the poorly drained soil apparently inhibited establishment. It was observed that, as the soil surface dried, soil ridges turned white with salts (Brady, 1974; Fipps, 1996). Depressions formed by packer wheels on seed drills might be beneficial for establishing salt-sensitive species by collecting water to leach salts away from the seed zone and by forming ridges away from the seed zone where salts may crystallize at the surface (Fipps, 1996).

Differences in initial stand density also existed among species (97% for alfalfa, 7% for birdsfoot trefoil, 50% for cicer milkvetch, 17% for crownvetch, 46% for kura clover, 82% for red clover, 64% for sainfoin, 60% for strawberry clover, and 18% for white clover, $LSD = 11$). Low initial stand density by birdsfoot trefoil might be an indication of lack of adaptation in the region or of the conditions imposed during establishment of these studies. Variety selection also could have been a factor. Guldan et al. (2000) and Lauriault et al. (2003, 2006), in north-central New Mexico, used ‘Norcen’ birdsfoot trefoil, which is apparently adapted to calcareous soils such as those used in these trials. Another factor in low

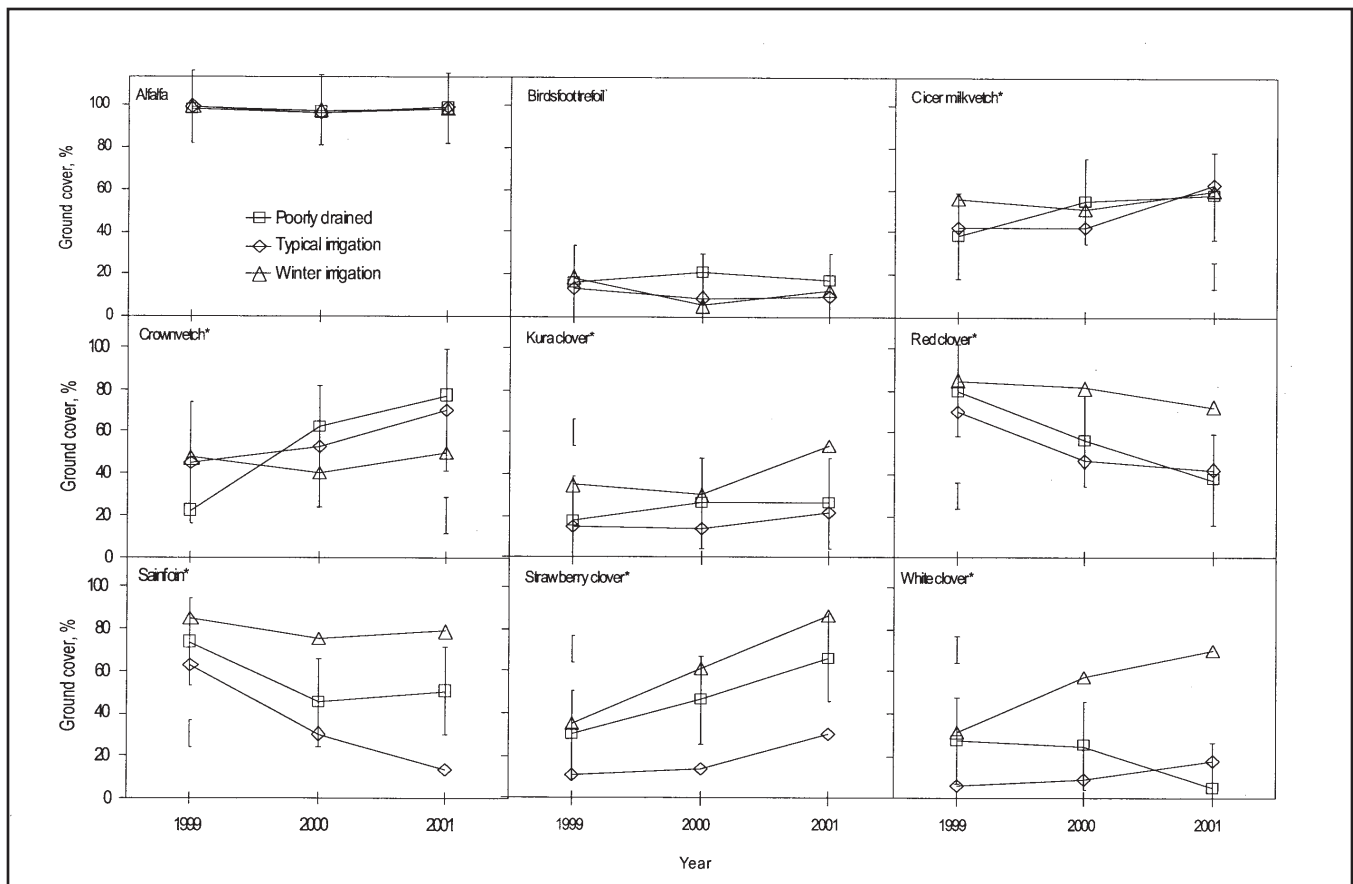


Figure 1. The difference over years in spring percentage ground cover of selected legumes grown under different soil moisture treatments at Tucumcari, New Mexico. Data are the means of four reps. Asterisked species indicates significant ($P < 0.05$) year x soil moisture treatment effect for that legume. Bars at series markers indicate the LSD ($P < 0.05$) for within-year comparisons of soil moisture treatments for each legume. Isolated bars indicate the LSD ($P < 0.05$) between years within any soil moisture treatment for that legume. Lack of that error bar indicates no significant difference over time for any soil moisture treatment or the mean across treatments for that species. *Poorly drained, typical irrigation, and winter irrigation* signify, respectively, poorly drained soil irrigated as needed to maintain a moist soil surface but generally less than once per harvest; furrow-irrigation once prior to each of six harvests taken May through October, which is typical to the region because that is when canal water is available; and same as typical irrigation but also irrigated monthly in winter (November to March) using ground water.

initial stand density of birdsfoot trefoil in the present study could be seeding rate. Guldan et al. (2000) sowed 25 kg ha^{-1} of pure live seed, nearly four times the seeding rate used for birdsfoot trefoil in the present study.

Low initial stand density for cicer milkvetch, crownvetch, kura clover, strawberry clover, and white clover was not a great concern because, as clone formers, these plants spread vegetatively by rhizomes or stolons (Beuselinck et al., 1994; Tracy and Sanderson, 2004). Reseeding by the crown formers—birdsfoot trefoil, red clover, and sainfoin—which spread only by reseeding or crown expansion, could thicken stands by those species

over time, if permitted (Beuselinck et al., 1994; Horton, 1994; Tracy and Sanderson, 2004).

By spring 1999, sown species began filling inter-row spaces, and observations of percentage ground cover were initiated (Figure 1). There was a considerable difference in response across years among soil moisture treatments within species for ground cover percentage from 1999 to 2001, leading to a year x soil moisture treatment x species interaction (Figure 1). Generally, percentage ground cover was highest for those legumes irrigated throughout the winter, followed by for those growing in poorly drained soil.

Alfalfa ground cover remained high throughout the study in all soil moisture treatments, while ground cover of birdsfoot trefoil remained consistently low (Figure 1). Cicer milkvetch and crownvetch ground cover increased over time in the poorly drained soil and under typical irrigation, but not when irrigated during the winter (Figure 1). Ground cover by kura clover remained unchanged over time in the poorly drained soil and under typical irrigation but increased when irrigated during the winter. Red clover and sainfoin decreased in percentage ground cover from 1999 to 2001 in all but the winter irrigation treatment (Figure 1). For sainfoin, the decline was greater under typical irrigation than in the poorly drained soil. Strawberry clover ground cover increased in all soil moisture treatments, but at different rates, with the least increase observed under typical irrigation and the greatest under winter irrigation. White clover ground cover percentage increased with winter irrigation, remained unchanged under typical irrigation and decreased in the poorly drained soil (Figure 1).

Beuselink et al. (1994) stated that plant persistence is critical during establishment, after which stand persistence becomes the concern. Alfalfa was the most stable species across soil moisture treatments in the present study. In a similar trial, also sown in late summer 1997 but irrigated only once after planting to promote germination, alfalfa was the only species to persist after the first production year and still had >80% ground cover in 2001 (Lauriault, unpublished data; Rumbaugh and Pedersen, 1979). Red clover plants can persist up to 5 yr under minimal physiological stress, but stand persistence is achieved by reseeding (Beuselink et al., 1994; Tracy and Sanderson, 2004). Birdsfoot trefoil and sainfoin also are short-lived perennials that spread and sustain stands by reseeding (Beuselink et al., 1994; Horton, 1994; Tracy and Sanderson, 2004). The frequent harvest interval in the present study might have prevented seed production by birdsfoot trefoil, red clover, and sainfoin (Beuselink et al., 1994; Lauriault et al., 2006; Tracy and Sanderson, 2004). Guldan et al. (2000) and Lauriault et al. (2003) observed that percentage of birdsfoot trefoil in the harvested sward increased through the eighth year of the stand under a lax 3-harvest system with harvests every other month. Harms et al. (2001) found birdsfoot trefoil to be stable across different management systems. In the present study, inhibited reseeding prevented ground cover increase by birdsfoot trefoil, but plants established at seeding appeared to be persistent (Figure 1). For red clover and sainfoin the stand also was not replenished and declined as plants from the original seeding perished.

The decline in sainfoin ground cover for all treatments from 1999 to 2000 (Figure 1) could be due to

below-average precipitation from October 1999 through nearly all of 2000 at this location (Table 1). Bolger and Matches (1990) measured lower ground cover percentages when irrigation levels were reduced near Lubbock, Texas. This also may be related to the difference between soil moisture treatments in the rate of decline in percentage ground cover for sainfoin (Figure 1). Continued decline in the typical irrigation treatment could be attributed to reduced soil moisture availability in that treatment compared to the other soil moisture treatments (Figure 1). Lack of supplemental water during winter and early spring in the poorly drained soil, which usually was kept moist by subsurface drainage from other irrigated fields, could have been a factor in the difference in response between the winter irrigation treatment and the poorly drained soil. As with birdsfoot trefoil and red clover, sainfoin did not reseed to replenish stands.

Generally, any increase in ground cover by the clone formers cicer milkvetch and kura clover was only slight during the study period (Figure 1). Among other clone formers, strawberry clover increased more dramatically in all soil moisture treatments, as did crownvetch in the poorly drained soil and white clover under winter irrigation. Similarly to red clover, white clover declined in ground cover percentage in the poorly drained borderline saline/sodic soil (Figure 1).

Guldan et al. (2000) and Lauriault et al. (2003) reported that the legume proportion of cicer milkvetch-tall fescue (*Festuca arundinacea* Schreb. = *Lolium arundinaceum* [Schreb.] S.J. Darbyshire) increased for three years then declined to approximately 15% cicer milkvetch in north-central New Mexico. Poor performance in poorly drained soils has been observed in crownvetch (Horton, 1994), but not in the present study. Performance by kura clover was better on similar soils in the higher elevations of north-central New Mexico, where it was found to be an aggressive spreader and a high yielder (Guldan et al., 2000; Lauriault et al., 2003). White clover is not as salt-tolerant as other species (Rogers et al., 1997b), but it does generally perform well in wet soils (Horton, 1994).

Moisture availability might have limited the spread of kura, strawberry, and white clovers such that nearly all of the plants of these species remained within the furrow, with very little encroachment to the bed tops, under typical irrigation compared to winter irrigation (Figure 1). Salinity might also have limited encroachment to bed tops by Kura and white clovers in the poorly drained soil (Rogers and Bailey, 1963; Brady, 1974; Fipps, 1996). Kura clover has not been shown to be adapted to calcareous soils (Rogers et al., 1997b), but it persisted at this location (Figure 1). Additionally, Rogers et al. (1997b) in Victoria, Australia, found kura clover

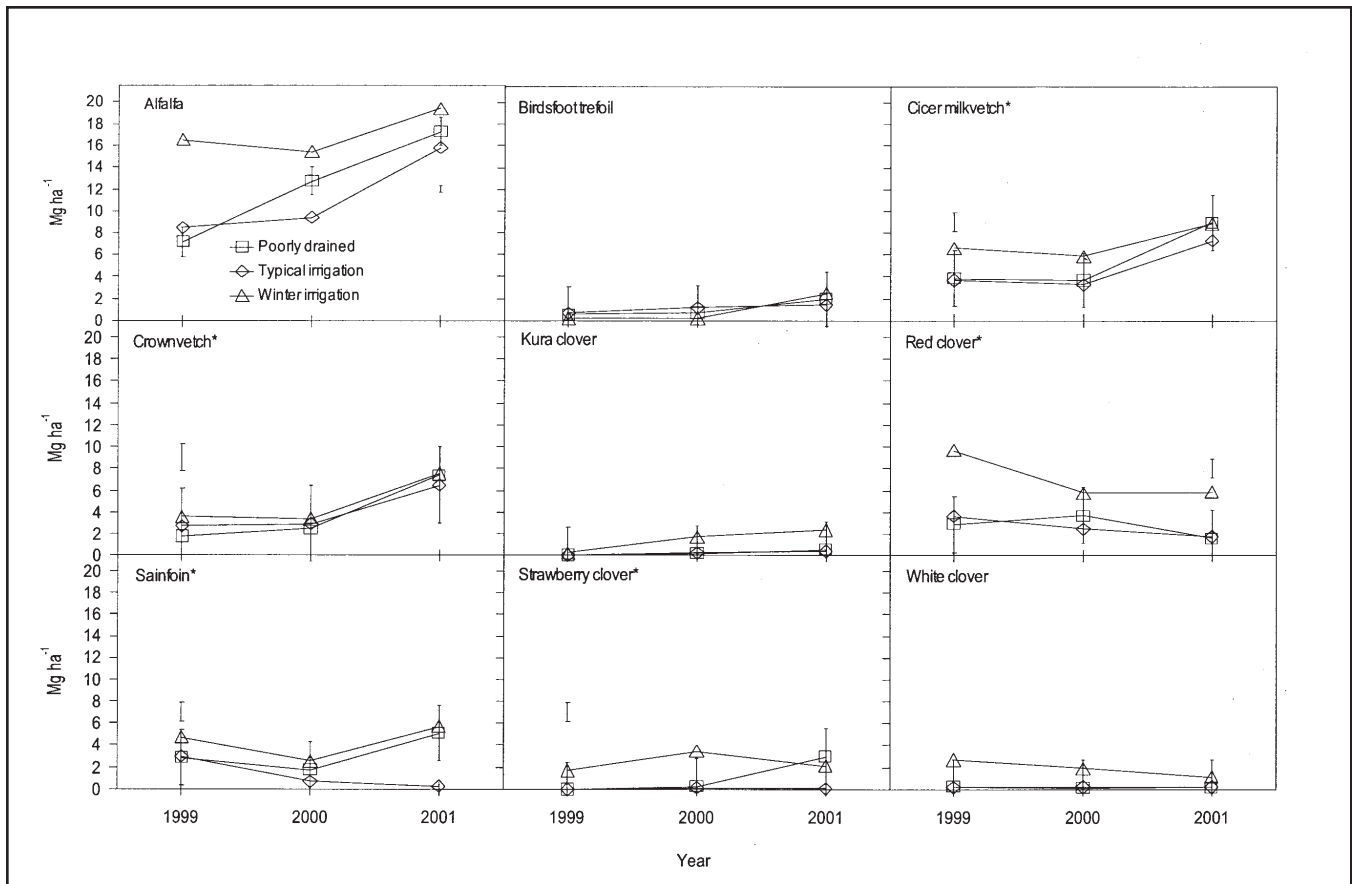


Figure 2. The difference over years in annual dry matter yield of selected legumes grown under different soil moisture treatments at Tucumcari, New Mexico. Data are the means of four reps and the total of six harvests. Asterisked species indicates significant ($P < 0.05$) year \times soil moisture treatment effect for that legume. Bars at series markers indicate the LSD ($P < 0.05$) for within-year comparisons of soil moisture treatments for each legume. Isolated bars indicate the LSD ($P < 0.05$) between years within any soil moisture treatment for that legume. Lack of that error bar indicates no significant difference over time for any soil moisture treatment or the mean across treatments for that species. *Poorly drained, typical irrigation, and winter irrigation* signify, respectively, poorly drained soil irrigated as needed to maintain a moist soil surface but generally less than once per harvest; furrow-irrigation once prior to each of six harvests taken May through October, which is typical to the region because that is when canal water is available; and same as typical irrigation but also irrigated monthly in winter (November to March) using ground water.

to be as salt tolerant as strawberry clover. Still, kura clover ground cover in the present study did not increase in the poorly drained, borderline saline/sodic soil as did strawberry clover (Figure 1).

Forage yield. Low plant stature (<10 cm above the tops of beds) of birdsfoot trefoil, kura clover, strawberry clover, and white clover, in addition to low initial stand density and subsequent ground cover, contributed to low yield. Indeed, total annual yields never exceeded 4 Mg ha⁻¹ yr⁻¹ (Figure 2) and, with few exceptions, indi-

vidual harvest yields rarely exceeded 0.5 Mg ha⁻¹ (Figure 3). Annual dry matter yields did not necessarily follow the pattern of ground cover for any species–soil moisture treatment combination (Figure 1). Generally, highest total annual yields were produced when the legumes were irrigated monthly throughout the winter (Figure 2). Yields in the poorly drained soil treatment often were not different from the typical irrigation treatment, but occasionally they were. Moisture in the poorly drained soil was mostly supplied by subsurface drainage from irrigation upslope, where the typical and winter

irrigation tests were located. Residual soil moisture after irrigation had ceased in the fall apparently helped increase—or at least maintain—ground cover in the poorly drained soil (Figure 1). Lack of supplemental water during winter and early spring may have led to little available water in the root zone of most species, possibly bringing about the general lack of difference in annual yield between the typical irrigation treatment and poorly drained soil (Figure 2).

The year \times soil moisture treatment \times species interaction for annual forage yield was caused by differences within all species except birdsfoot trefoil, kura clover, and white clover (Figure 2). Yields of alfalfa, cicer milkvetch, and crownvetch increased in all soil moisture treatments. Red clover yield remained unchanged in the poorly drained soil and under typical irrigation, but decreased when irrigated during the winter, although yields under winter irrigation usually remained greater (Figure 2). Sainfoin yields declined over time in the typical irrigation treatment, while non-significant declines in the other two treatments from 1999 to 2000 were followed by a significant increase from 2000 to 2001 to a level not different from 1999. Strawberry clover annual yields did not change under typical or winter irrigation, but there was an increase from 2000 to 2001 in the poorly drained soil (Figure 2). The increase over time in ground cover percentage for strawberry clover for both the typical and winter irrigation treatments did not result in an increase in annual dry matter yield (Figures 1 & 2). A similar observation can be made about white clover under winter irrigation.

As with percentage ground cover, significant year \times soil moisture treatment interactions for cicer milkvetch and crownvetch may not be biologically significant due to general lack of differences within years. For both of these species, ground cover and annual dry matter yield followed similar patterns across years, having no differences between soil moisture treatments within any year, demonstrating the versatility of these two species across a variety of soil moisture situations. As with alfalfa, there may be a benefit, however, of increasing yield of cicer milkvetch early in stand life by irrigating during the winter during the first two or three years after seeding in the Southern High Plains. Winter irrigation likely does not enhance the stand density and dry matter yield of crownvetch, but it is necessary throughout the stand life of red clover to maintain stands and provide higher yields (Figures 1 & 2).

The general increase in yield during early stand life by irrigated alfalfa (Figure 2) has been observed elsewhere in New Mexico (Guldan et al., 2000) and for other species in rainfed areas (Harmony et al., 2001). Lauriault et al. (2006) observed a year-to-year change in

yield of alfalfa and kura clover similar to that generally observed for alfalfa, cicer milkvetch, crownvetch, and sainfoin (Figure 2). The year-to-year changes in yield of sainfoin (Figure 2) closely followed changes in ground cover percentage (Figure 1). In other studies (Lauriault et al., 2006; Loiseau et al., 2001), a biennial pattern in year-to-year yield variation by nodulated legumes has been attributed to soil nitrogen status. In the present study, it is likely more related to precipitation—2000 was very dry compared to previous years (Table 1)—based on the increase in yield of alfalfa in 2000 in the poorly drained soil (Figure 2). Subsurface drainage from other irrigated fields likely provided water that was available to the deep-rooted alfalfa but not as available to the other more shallow-rooted species tested.

The harvest \times soil moisture treatment \times species interaction also was significant (Figure 3) because irrigating in winter increased yield of the first and sometimes subsequent harvests compared to the other two soil moisture treatments for all species except birdsfoot trefoil. When sliced by species the harvest \times soil moisture treatment also was not significant for white clover. As with annual yields (Figure 2), differences between the typical irrigation treatment and the poorly drained soil occurred only with alfalfa, sainfoin, and strawberry clover.

Continued higher yields in the second and even subsequent harvests by several species (alfalfa, red clover, and sainfoin) suggest a surplus of water from the winter irrigation treatment that was still available for use by those species but not available to the other legumes tested, likely because it was below their rooting zone. Alternatively, winter irrigation from the first winter after planting could have limited root system development in some species by not forcing plants to more deeply explore the soil profile for water, as plants of those species in the typical irrigation treatment may have done. Then, during periods of high water demand, such as summer, winter-irrigated plants would not have as great an access to the soil profile as those having to explore for water during the drier summer months. Differences between perennial cool-season grasses also have been observed due to winter irrigation. Lauriault et al. (2005b) observed a benefit in the first harvest from winter irrigation of tall fescue only, while fall stockpile yields of Altai wildrye (*Leymus angustus* [Trin.] Pilg.) were reduced by irrigation applied the previous winter.

Early-season yields of alfalfa were greater than mid-season yields in poorly drained soil and under typical irrigation in this study (Figure 3) and are atypical of similarly managed established alfalfa at this and other locations in New Mexico (Lauriault et al., 2003, 2005a; Tapia and Lugg, 1986). Generally, because of low precipitation during late winter and early spring in the

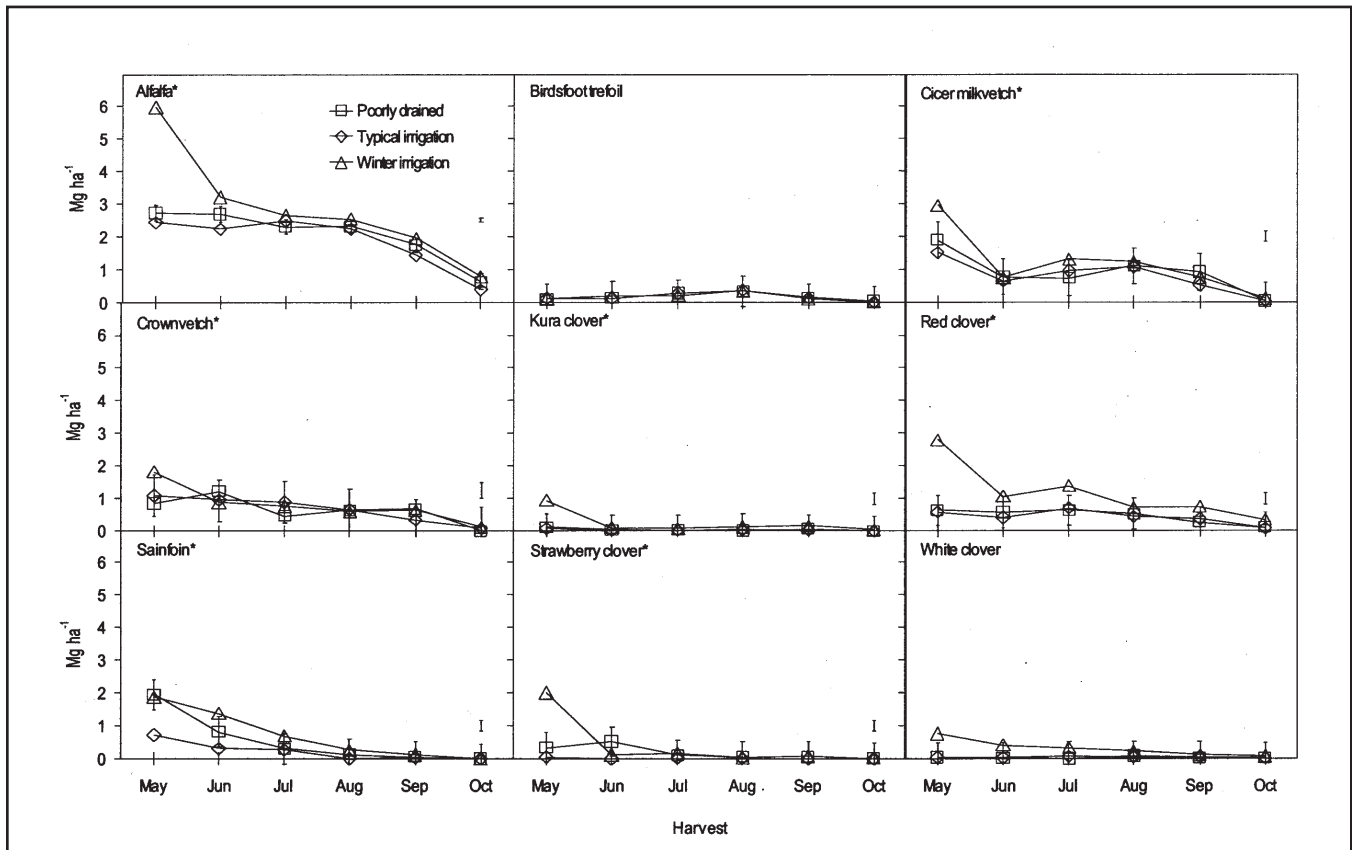


Figure 3. The difference in seasonal distribution of yield of selected legumes grown under different soil moisture treatments at Tucumcari, New Mexico. Data are the means of three years and four reps. Asterisked species indicates significant ($P < 0.05$) harvest x soil moisture treatment effect for that legume. Bars at series markers indicate the LSD ($P < 0.05$) for within-harvest comparisons of soil moisture treatments for each legume. Isolated bars indicate the LSD ($P < 0.05$) between harvests within any soil moisture treatment for that legume. Lack of that error bar indicates no significant difference over time for any soil moisture treatment or the mean across treatments for that species. *Poorly drained*, *typical irrigation*, and *winter irrigation* signify, respectively, poorly drained soil irrigated as needed to maintain a moist soil surface but generally less than once per harvest; furrow-irrigation once prior to each of six harvests taken May through October, which is typical to the region because that is when canal water is available; and same as typical irrigation but also irrigated monthly in winter (November to March) using ground water.

Southern High Plains (Table 1), active growth by alfalfa is delayed in the region until irrigation water is available and applied, which for the present study was only three to four weeks before the first harvest (except in 2001 when it was after the first harvest).

High early-season yields are typical for sainfoin (Figure 3; Bolger and Matches, 1990; Tapia and Lugg, 1986). While it was not readily apparent in the present study, more rapid yield decline across the season than for other legumes is a limitation for sainfoin (Figure 3; Tapia and Lugg, 1986), requiring supplementation with hay or pastures of other species to provide season-long feed. It is not well understood why first harvest yields

of sainfoin in the poorly drained soil were numerically equal to those of sainfoin irrigated during winter rather than being similar to the typical irrigation treatment, as was the case for all other species (Figure 3). Surface water for irrigation is only available via canal from late April until October, and that is when the poorly drained soil remained moist due to subsurface drainage from other irrigated fields. Additionally, as previously stated, the first harvest each year was often taken only 3 to 4 weeks after the first irrigation using canal water, except in 2001, when it was not applied until after the first harvest. Higher yields in the second harvest for strawberry clover on the poorly drained soil (Figure 3) likely reflect

its adaptation to wet/saline/sodic conditions (Rogers et al., 1997b).

Rehm et al. (1998) stated that any lack of relationship between stand density and yield indicates that stand density is not limiting productivity. Consistent season-long low yields by birdsfoot trefoil across soil moisture treatments (Figure 3) are likely due to low plant numbers each year (Figure 1) and low plant stature, which also was a factor in low measured yields of kura, strawberry, and white clovers. Seed production by birdsfoot trefoil was inhibited by harvest frequency (Lauriault et al., 2006; Tracy and Sanderson, 2004) as well as low plant stature. If reseeding had been permitted by a longer harvest interval, ground cover percentage might have increased (Figure 1), but yields would still likely have been too low to be considered for hay harvest. Declining annual yield of red clover and sainfoin under typical irrigation, although not significant for red clover in this study, is related to plant death as indicated by decreasing ground cover percentage (Figures 1 & 2; Heichel et al., 1985; Rehm et al., 1998).

As clone-formers (Beuselink et al., 1994), cicer milkvetch, crownvetch, kura clover, strawberry clover, and white clover should have increased in yield as the stand filled and low daughter plant numbers did not limit productivity (Figures 1 & 2; Rehm et al., 1998). Yields of cicer milkvetch and crownvetch increased across years, but those of kura, strawberry, and white clover did not (Figure 2). Unlike high-yielding plants of kura clover in other regions (Sheaffer and Marten, 1991; Guldan et al., 2000), in the present study kura clover, like birdsfoot trefoil, was smaller in stature (Rogers et al., 1997b), mostly below the cutting height of 7.5 cm above the tops of the beds. This was also true of strawberry and white clover plants. Additionally, these species mainly grew in the furrow, either because of greater water availability or salt avoidance. Consequently, even if complete ground cover had been developed by kura, strawberry, and white clover, like birdsfoot trefoil they likely would not have produced significant hay yields.

Low yield does not necessarily mean low value (Clark, 2001). While much of this forage was inaccessible to harvesting equipment, grazing animals can harvest forage with lower plant height, as well as from the lower elevation of the furrow. Additionally, Lauriault et al. (2006) found that birdsfoot trefoil–tall fescue and cicer milkvetch–tall fescue pasture yields were not depressed compared to monoculture tall fescue + 134 kg N ha⁻¹, even when the legume DM proportion was <20% of the harvested total mixture DM. Similar results for birdsfoot trefoil, but not for cicer milkvetch, were observed under 3-harvest hay management (Lauriault et al., 2003).

Low yield is not as great a concern if the need is for ground cover rather than for forage production (Clark, 2001). As salt-tolerant (Rogers et al., 1997b) clone-formers, strawberry clover and possibly cicer milkvetch and crownvetch have considerable value in low-maintenance areas and for stabilization of marginal lands. Birdsfoot trefoil, red clover, and sainfoin also might have value in these situations, if permitted to reseed.

Of the species tested, alfalfa had highest yields and, except for higher yields in the early harvests due to winter irrigation, it continued to produce higher yields across the season for all soil moisture treatments imposed (Figure 3; Lauriault et al., 2003, 2005a; Tapia and Lugg, 1986). Annual yields of alfalfa from three harvests per year (May, June, and July during 1999 to 2001) in the trial irrigated only once after planting were approximately 1/3 of those reported here (Figure 2; Lauriault, unpublished data).

Long-term stand persistence is a concern with alfalfa in sustainable systems (Guldan et al., 2000). Although individual plants can survive for long periods (Lauriault et al., 2003, 2006; Rumbaugh and Pedersen, 1979) and anecdotal reports of 20-year-old alfalfa stands are common in this region, autotoxic effects of alfalfa limit re-establishment without a significant waiting period (Beuselink et al., 1994; Hegde and Miller, 1990). This often requires rotation to another crop that is not susceptible to the allelopathy, which is not generally a viable option in pasture systems. Thus, alternative species can be used to fill the time between stand depletion and re-establishment of alfalfa without crop rotation. Additionally, the alternative legumes could be used to replace the alfalfa altogether, if lower yields are acceptable (Figure 2; Lauriault et al., 2006).

CONCLUSIONS

Birdsfoot trefoil performed poorly as rapidly spreading ground cover under the management imposed, although individual plant persistence was good. Kura clover, strawberry clover and white clover did perform well as a ground cover when irrigated year-round. Strawberry clover established and increased good ground cover in borderline saline/sodic conditions, but white clover did not. None of these three clovers or birdsfoot trefoil attained plant height sufficient to produce hay. If low initial stand density like that observed for birdsfoot trefoil in the present study could be overcome through better varietal selection or improvement for local adaptation, birdsfoot trefoil could possibly have value in low-maintenance systems in the Southern High Plains.

Alfalfa was the most consistent in percentage ground cover across years and had highest DM yields. With

some limitations and lower yields, cicer milkvetch, crownvetch, red clover, and sainfoin offer alternatives during periods of alfalfa stand decline and re-establishment or as replacements altogether in the Southern High Plains.

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