Morphological and physiological variation among ecotypes of sweetvetch (*Hedysarum boreale* Nutt.)

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Abstract

This study considered seedling establishment characteristics, nitrogen fixation capability, nutritive value, and clustering relationships among 11 putative ecotypes of sweetvetch (*Hedysarum boreale* Nutt.). A total of 44 morphological and physiological variables were evaluated in greenhouse and field experiments. Sweetvetch root systems had large nodules that were capable of fixing nitrogen, a potentially useful attribute in the reclamation of nitrogen-limited environments such as mine spoils in the western United States. Sweetvetch provided forage during the spring and summer, but little forage was available during the fall and winter. An ecotype collected near Orem, Utah, exhibited superior seedling establishment characteristics under mesic conditions while an ecotype from near Duchesne, Utah, established well under xeric conditions. An ecotype from Hobble Creek, Utah, showed superior rhizome development, a potentially useful characteristic for stabilizing highly erodible areas. Although cluster analysis procedures indicated differences among the ecotypes, this clustering was not always clearly related to characteristics of the collection site. Sufficient genetic diversity was present among ecotypes to assure adaptation to a wide array of sites and to facilitate improvement through breeding and selection.

Key Words: Utah sweetvetch, northern sweetvetch, legume, forage, nitrogen fixation, seedling establishment, seed production

Introduced forbs are becoming more widely used in rangeland seedings in the Intermountain West (Wasser 1982, Shaw and Monsen 1983). 'Appar' lewis flax (*Linum lewesii* L.), 'Delar' small burnet (*Sanguisorba minor* Scop.), yarrow (*Achillea millefolium* L.), several penstemons (*Penstemon* spp.), globemallows (*Sphaeralcea* spp.), cicer milkvetch (*Astragalus cicer* L.), alfalfa (*Medicago sativa* L. and *M. falcata* L.), biennial sweet clovers (*Melilotus officinalis* Lam. and *M. alba* Medikus), and sainfoin (*Onobrychis viciifolia* Scop.) are some of the more commonly used forbs in the semiarid Intermountain West. Herbaceous legumes native to the Intermountain West have not been widely used in seeding arid and semiarid rangelands because of questionable forage value, limited seed availability, and livestock toxicity problems (Rumbaugh 1983).

Sweetvetch (*Hedysarum boreale* Nutt.) is a perennial legume species that is native to the Intermountain West and has received some attention as a possible species for use in revegetating Intermountain rangelands. Sweetvetch was first described in 1818 (Redente 1980). The name "sweetvetch" is synonymous with Utah sweetvetch and northern sweetvetch. The most recent and complete description of the *H. boreale* complex was by Northstrom and Welsh (1970), as revised by Northstrom (1976). Sweetvetch growth in the early spring provides a considerable amount of palatable early spring forage for big-game and domestic livestock, and no toxicity problems have been reported for sweetvetch (Plummer et al. 1968). Improper grazing has apparently eliminated sweetvetch from much of its original distribution (Plummer et al. 1968). Because sweetvetch is widely distributed throughout the foothill and lower mountain elevations of the Intermountain West and apparently exhibits considerable ecotypic variation for many characteristics, it may be useful in the revegetation of a wide diversity of sites (Redente and Reeves 1981). The use of sweetvetch for revegetation has been limited, primarily because seed commonly is harvested from wildland stands and, consequently, seed production is erratic and seed is expensive. As a legume, sweetvetch may also improve the nitrogen status of rangeland soils through biological nitrogen fixation.

The primary objective of this study was to evaluate 11 diverse ecotypes of sweetvetch for their seedling establishment characteristics, nitrogen fixation capability, and nutritive value. This study also evaluated relationships among the 11 ecotypes by cluster analysis.

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Cooperative investigations of the USDA Agricultural Research Service, the USDA Forest Service, and the Utah Agricultural Experiment Station. Journal Paper 3717.
Manuscript accepted 13 February 1989.

Materials and Methods

Seed Sources

Seeds of 11 sweetvetch populations (putative ecotypes) were obtained from a broad range of collection sites (Table 1). This original seed was used in both the greenhouse and field experiments. Seed from the Hobble Creek Utah site, (Ecotype 7) and the Ballard Mine, Idaho site (Ecotype 4) came from plants established from seed from Orem, Utah, site (Ecotype 5) in 1963 and about 1965, respectively.

Table 1. Ecotype identification number, collection location, and collection site characteristics for 11 ecotypes of sweetvetch.

		Site characteristics		
Ecotype identification-number	Collection location	Elevation (m)	Soil texture	Annual precipitation (cm)
1	Benmore, UT	1,739	Clay loam	33
2	Arco, ID	1,525	Silty loam	28
3	Duchesne, UT	1,525	Loam	33
4	Ballard Mine, ID	2,074	Mine dump	48
5	Orem, UT	1,586	Cobbly loam	38
6	Salt Lake City, UT	1,586	Upland stony	46
7	Hobble Creek, UT	1,556	Stony loam	42
8	Moab, UT	1,373	Sandy	19
9	Garden City, UT	1,830	Mountain Loam	57
10	Musselshell Co., MT	1,586	Loam	54
11	Rio Blanco Co., CO	1,739	Loam	33

Greenhouse Experiment (Seedling Establishment Characteristics)

Seeds were removed from the loments, mechanically scarified, and inoculated with approximately 0.1 g of *Rhizobium* (*Hedysa-*

rum Spec. 2 inoculum, Nitragin Co.[1], Milwaukee, Wis.) per 250 seeds. They were sown in containers (length 20 cm, volume 195 cc) filled with a mixture of 1/3 sand, 1/3 peat, and 1/3 loam soil on 26 March 1984. The plants were propagated in a greenhouse maintained at approximately 30/15° C day/night temperature regime with no supplemental lighting. Plants were kept watered at near field capacity for 35 days before being placed under a greenhouse line-source sprinkler system on 30 April 1984. The greenhouse line-source sprinkler system has a sprinkler nozzle that traverses along a central line above a groundbed and applies an amount of water that decreases as distance from the central line increases (Johnson et al. 1982). Ten plants from each ecotype were placed at equal intervals along the irrigation gradient in 3 replications using a randomized complete block design. Total water applied during the approximate 38-day growth period along the gradient ranged from 9.80 cm (123 ml) to less than 0.04 cm (0.5 ml). Surviving plants were combined into 3 groups according to the total amount of water applied. The 3 groups represented abundant water (plants 1 through 3), adequate water (plants 4 through 6), and limited water (plants 7 through 9); mean total water application in the groups was 8.7, 4.2, and 1.2 cm, respectively. Virtually all plants at the tenth position on the gradient died and were not included in the analysis.

During 6 to 8 June 1984, leaves were removed from the seedlings under the line-source sprinkler and leaf area measured with a Licor[1] area meter. Stems, petioles, and leaves were then oven-dried at 75° C for 48 h and weighed. Nitrogen fixation was estimated on a whole plant and specific nodule activity basis by the acetylene reduction procedures described by Johnson and Rumbaugh (1981). Each root system was extracted from the soil without washing and placed in a 60-cc plastic syringe. The syringe was filled with 54 cc of ambient air and 6 cc of washed commercial acetylene, creating an atmosphere of 10% acetylene and 90% air. Gas samples were incubated 1 h at ambient temperatures and shielded from direct sunlight. After incubation, 11 cc gas aliquots were injected from the syringes into 10 ml stoppered Vacutainers[1]. Ethylene content of the gas sample was determined using a gas chromatograph equipped with dual hydrogen-flame ionization detectors maintained at 150° C.

The root systems were then washed and root lengths measured with a Comair[1] root scanner. Nodules were removed from the roots and counted. Roots and nodules were then oven-dried at 75° C for 48 h and weighed. Total acetylene reduction activity was expressed as moles of ethylene per hour for the whole root system, whereas specific nodule activity was expressed as moles of ethylene per gram of nodule dry weight. Data were analyzed by analysis of variance, correlation, and multivariate procedures. Least significant difference (LSD) values were computed to evaluate differences among means.

Field Experiments (Mature Plant Characteristics and Seed Production)

For the field portion of the study, seeds from each sweetvetch ecotype were inoculated with rhizobia, germinated, and grown as in the greenhouse experiment for approximately 30 days prior to transplanting. Plants of NC-83-1 alfalfa (Kehr et al. 1975) served as a standard for comparison. Plants were transplanted in June, 1983, at a site 2 km south of Logan, Utah. Plants were placed 1 m apart in one-plant plots with additional plants providing one-row borders to separate the seed production experiment and the destructive harvest experiment. The first experiment measured seed production resulting from open-pollination and consisted of 8 replications arranged in a randomized complete block design. For the seed weight measurements, seed was bulked over replications within ecotypes and 4 aliquots of 25 seeds of each ecotype were weighed. The second experiment quantified root and shoot biomass, root length, nitrogen fixation activity, and forage quality. Fifteen replications of single plant plots were arranged in a randomized complete block design. Some plant mortality occurred, but an average of 12 plants were harvested for each ecotype. Soil at the site is a uniform Nibley silty clay loam (fine, mixed, mesic, Aquic Argiustoll) with 0 to 3% slopes. Precipitation at the site occurs primarily as winter snow and spring rain and averages 44.2 cm annually (United States Department of Agriculture 1974). During the 2 years of the experiment, the annual precipitation was 77.2 cm and 48.0 cm, respectively.

Plants of each ecotype were harvested during 20–23 June and again during 4–6 October 1984. Ten adjoining replications were excavated the first harvest to minimize damage to plants that were to be excavated at the second harvest. A tractor-mounted tree lifter was used to cut the root systems at a depth of approximately 35 cm. Plants were then carefully removed from the soil by hand to recover the root systems. This resulted in an excavated soil block that was approximately 55 cm long, 45 cm wide, and 35 cm deep for each plant. Nodulated root sections were placed in 120 cc syringes and nitrogen fixation was estimated for each accession using the previously described acetylene reduction technique. Roots and shoots were weighed fresh, oven dried for 72 h at 65° C, and reweighed for dry weight.

Four plants of each ecotype were randomly selected from the excavated plants for forage quality analysis. Shoots of these plants were ground in a Wiley mill using a 1 mm screen and placed in air-tight Mason jars until analysis for percent nitrogen by the macro-Kjeldahl technique (Harris 1970). The nitrogen content was multiplied by 6.25 to estimate crude protein percent. In vitro dry matter digestibility (IVDMD) for these plants was estimated using rumen fluid from a Holstein heifer fed an alfalfa hay diet. A 48-h fermentation period with the strained rumen fluid was followed by a 48-h incubation in hydrochloric acid-pepsin solution.

Differences among ecotypes detected by analysis of variance procedures were tested for significance using the LSD procedure. Data from the greenhouse and field experiments were combined (44 attributes) and taxonomic distances and clustering among the ecotypes computed by the unweighted pair-group method using arithmetic averages of standardized data (Rohlf 1987).

Results and Discussion

Greenhouse Experiment

In the Intermountain West adequate soil moisture is usually available for imbibition and germination, but seedling establishment and growth can be severely impaired by dry conditions during early summer. The greenhouse experiment simulated growth conditions during this early summer period. Little mortality occurred under the abundant and adequate water level treatments. Under drought stress in the limited water application treatment level, mortality was 30%.

Sweetvetch shoot mass decreased as less water was applied, whereas root mass was greatest at the adequate level of water application (Table 2). Significant differences were observed among the ecotypes for both shoot and root mass. Ecotype 5 had the greatest shoot and root mass at the abundant water level, while Ecotype 3 had the greatest root mass and the second greatest shoot mass at the limited water level (data not shown). Some ecotypes, e.g. Ecotype 1, maintained relatively constant shoot, root, and total biomasses as less irrigation water was applied, but the mass of other ecotypes, e.g., Ecotype 11, declined markedly when less water was applied (data not shown).

The proportion of root mass to total plant mass increased as less

[1]Mention of a trademark, proprietary product, or vendor does not constitute guarantee or warranty of the product by the U.S. Department of Agriculture and Utah State University, and does not imply approval to the exclusion of other products or vendors that may also be suitable.

Table 2. Shoot mass, root mass, total root length, green leaf area, nodule mass, number of nodules, plant acetylene reduction activity, and specific nodule activity of 11 sweetvetch ecotypes at 3 water levels under the greenhouse line-source sprinkler system. Each value represents the mean of 9 observations for the abundant and limited water levels and 12 observations for the adequate water level for each ecotype.

Trait	Water level	Mean	Range of ecotype means	Significance of F tests[1]: Differences among ecotype means	Significance of F tests[1]: Water levels by ecotypes
Shoot mass (mg $plant^{-1}$)					**
	Abundant	50	31 – 78	*	
	Adequate	42	31 – 98	*	
	Limited	21	9 – 31	*	
Root mass (mg $plant^{-1}$)					**
	Abundant	54	33 – 76	*	
	Adequate	60	37 – 86	*	
	Limited	31	11 – 49	*	
Root length (m $plant^{-1}$)					**
	Abundant	1.36	0.80 – 1.77	*	
	Adequate	1.63	1.10 – 2.09	*	
	Limited	0.87	0.31 – 1.38	*	
Green leaf area (cm^2 $plant^{-1}$)					**
	Abundant	4.3	2.1 – 7.0	*	
	Adequate	3.0	2.1 – 3.8	*	
	Limited	1.0	0.4 – 1.8	NS	
Nodule mass (mg $plant^{-1}$)					**
	Abundant	7.2	2.5 – 11.5	*	
	Adequate	5.9	3.2 – 9.4	*	
	Limited	2.9	1.2 – 5.3	*	
Nodules (number $plant^{-1}$)					NS
	Abundant	9.3	3.4 – 15.2	*	
	Adequate	8.3	4.3 – 13.6	*	
	Limited	4.7	2.0 – 9.4	*	
Plant acetylene reduction activity (nmol C_2H_4 $plant^{-1}s^{-1}$)					**
	Abundant	0.381	0.178 – 0.769	*	
	Adequate	0.244	0.183 – 0.356	*	
	Limited	0.039	0.008 – 0.089	NS	
Specific nodule activity (nmols C_2H_4 s^{-1} g^{-1} nodule dry weight)					NS
	Abundant	67.7	12.8 – 110.0	NS	
	Adequate	54.0	27.6 – 83.5	NS	
	Limited	9.1	1.3 – 21.6	NS	

[1]NS, *,**Not significant and significant at the 0.05 and 0.01 levels, respectively.

water was applied. Total biomass remained relatively constant for the abundant and adequate water levels. Average root/shoot ratios were 1.1, 1.4, and 1.5 at the abundant, adequate, and limited water levels, respectively. Total root length is an estimate of the soil volume that the roots occupy, whereas root mass indicates belowground carbon and nutrient investment. Similarly, green leaf area indicates the seedling photosynthetic area, whereas shoot mass indicates the aboveground shoot carbon and nutrient investment. As less water was applied, the green leaf area, and thus transpirational area, decreased (Table 2). Total root length increased from the abundant to the adequate water level, but declined markedly at the limited water level. Under moderate water stress sweetvetch roots apparently increased the soil volume explored as soil moisture was depleted. Total root length and green leaf area differed significantly among ecotypes. Ecotype 5 tended to have the greatest root length and the most leaf area at the abundant and adequate water levels, while Ecotype 3 exhibited the greatest root length and most abundant green leaf area at the limited level (data not shown).

To ensure successful seedling establishment, a seed should germinate quickly and initiate radical cell elongation and subsequent root development rapidly (Blaisdell 1949, Platt and Weis 1985). The seedling root needs to quickly explore a large soil volume and penetrate the soil profile as deeply as possible to aid in water uptake as the soil profile dries. Consequently, total seedling root length is probably an important screening characteristic for successful establishment in semiarid environments.

Green leaf area could potentially be an important screening characteristic and aid establishment success of sweetvetch. During high soil moisture periods, production of photosynthetic leaf area would be important to optimize carbon gain during favorable growing conditions. During drying periods, a plant that can maintain green leaf area and photosynthetic activity may be able to grow for a longer period and take advantage of additional precipitation. As a result, greater green leaf area at both higher and lower moisture levels probably confers a competitive advantage.

Nitrogen fixation is a unique biological process that may be beneficial to plants growing in nitrogen-limited environments. This benefit may be magnified during seedling establishment when rooting density is minimal. However, the energy required for nitrogen fixation may mean that it may be one of the first plant functions curtailed during drought. Consequently, it is important to determine if sweetvetch ecotypes vary in their ability to fix nitrogen under water stress.

The number of nodules remained relatively constant for the first 8 plants along the water gradient, indicating that this trait was quite tolerant to decreasing water availability. Ecotypes differed significantly within each of the water levels, and their relative rankings were consistent over the 3 water levels (Table 2). Nodule mass was reduced by 18% from the abundant to adequate water level and by an additional 51% from the adequate to the limited water level. Ecotypes 2, 4, and 5 had the most nodules and nodule mass at the abundant level of water application, and Ecotype 3 had the most nodules and nodule mass at the limited level of water application (data not shown). Because nodule mass decreased with declining water, sweetvetch apparently allocates fewer resources to nodules as water becomes limiting.

Total plant and specific nodule acetylene reduction activities (Table 2) decreased with the decline in water between the abundant and adequate water levels and were reduced sharply between the adequate and limited water levels. Similar to nodule mass, acetylene reduction activity on both a whole plant and a specific nodule basis appeared more sensitive to drought than the other plant characteristics. Ecotypes 4 and 5 had the greatest acetylene reduction activity per plant at the abundant water level, but activities were not significantly different at the limited water level (data not shown). Specific nodule activity did not differ among ecotypes. The interaction of ecotypes and water levels was significant ($P<0.01$) for activity on a whole plant basis but not significant ($P>0.05$) on a nodule dry weight basis.

Field Experiments

Seed weights of the original collections and of the open-pollination increases varied significantly ($P<0.05$) among ecotypes (Table 3). Probably because growth conditions were more favorable at the experimental location than at the sites of origin, weights for 25 seeds from the open-pollination increases of the 11 ecotypes were heavier (mean of 0.234 g) than seeds from the original collections (mean of 0.195 g). Although the rankings of ecotypes according to seed weight changed between seed generations, the 5 ecotypes in the original collection that produced the heaviest seed also produced the heaviest seed in the open-pollination increases. Spearman's rank correlation ($r_s = 0.73$, $P<0.05$) indicated an association between the 2 types of seeds.

In the greenhouse experiment, Ecotype 5 exhibited the best seedling growth at the abundant water level (data not shown) and also had one of the highest seed weights (Table 3). Conversely,

Table 3. Seed weights of 11 sweetvetch ecotypes for 25 seeds from the original collection sites and their seed weights and seed production when grown in a uniform test environment. Each seed weight value is the mean of 4 replications and each seed production value is the mean of 8 replications[1].

Ecotype identification number	Seed weight (g 25 seeds^{-1}) Original collection	Test environment	Seed production (g plant^{-1})
1	0.166 fg	0.226 de	4.3 bc
2	0.199 d	0.211 ef	3.6 bc
3	0.137 h	0.213 ef	3.2 bc
4	0.243 a	0.271 ab	2.8 bc
5	0.223 b	0.278 a	9.0 a
6	0.228 ab	0.260 abc	5.8 ab
7	0.203 c	0.272 ab	3.0 bc
8	0.229 ab	0.255 bc	0.1 c
9	0.188 de	0.239 cd	3.3 bc
10	0.149 gh	0.149 g	0.2 c
11	0.176 ef	0.199 f	1.6 bc
Mean	0.195	0.234	3.4

[1]Means in the same column that are followed by a different letter are significantly different by LSD at the 0.05 level.

Ecotype 3, which showed the best seedling growth at the limited water level (data not shown), had one of the lowest seed weights (Table 3). These results indicate the heavier seeds may be important in screening for environments where precipitation is equivalent to the abundant and adequate water treatment levels, but may not be a desirable characteristic in screening for drought resistance. Similarly, Wright and Brauen (1971) found that Lehman lovegrass (*Eragrostis lehmanniana* Nees) lines with the heaviest seeds were generally the most drought susceptible.

Seed weight is positively correlated with germination rate and seedling vigor in several plant species (Erickson 1946, Kneebone and Cremer 1955, Beveridge and Wilsie 1959, Fransen and Cooper 1976, Asay and Johnson 1980) and has been used to screen for seedling vigor in several forage grasses (Tossell 1960, Asay and Johnson 1980). Seed weights of the 11 sweetvetch populations from the original collections were indicative of their seed weights when the populations were grown in a uniform environment. However, because of the uniform environment, the open-pollination seed weights probably more accurately reflect the magnitude of the genetic differences among the accessions.

Although some plants flowered, no viable seed was produced during the initial establishment year. Plants produced seed in their second growing season in the field nursery, and ecotypes differed significantly ($P<0.05$) in seed yields (Table 3). Ecotype 5, originally from a site receiving an intermediate level of precipitation, produced the most seed in the test environment, while Ecotype 8 from the most arid site produced the least seed.

In the second field experiment plants were destructively harvested during their second growing season to estimate forage availability in early summer and fall. At the first harvest all sweetvetch ecotypes were in full bloom, whereas alfalfa was at one-tenth bloom. This difference in maturity limits the ability to directly compare alfalfa and sweetvetch. Sweetvetch provided more forage at the first than at the second harvest (Table 4); however, alfalfa produced significantly ($P<0.01$) more forage than any sweetvetch ecotype at both harvests and more than 850% more forage than the most productive sweetvetch ecotype at the second harvest. Ecotype 7 produced the most forage annually (237 g), and Ecotype 9 produced the least (86 g). Significant differences ($P<0.05$) in forage yields occurred among ecotypes at the first harvest but not at the second harvest.

Percent crude protein did not vary significantly among the sweetvetch ecotypes at the first harvest but did at the second harvest (Table 4). Alfalfa contained a higher percentage of protein and greater total crude protein than any sweetvetch ecotype at both harvests. Sweetvetch ecotypes differed significantly ($P<0.05$) in total crude protein at the first harvest but not at the second harvest. Alfalfa tended to have a higher in vitro dry matter digestibility (IVDMD) than any of the sweetvetch ecotypes at the first harvest, but Ecotypes 8 and 10 were slightly more digestible than alfalfa at the second harvest. Ecotypes differed significantly ($P<0.05$) in IVDMD at the first but not the second harvest.

At the second harvest sweetvetch was much less valuable as a fall forage than alfalfa (Table 4). At this harvest most of the sweetvetch plants had senesced and had very few leaves. In addition, sweetvetch growth at this harvest was prostrate and would be difficult to graze, particularly if covered by snow. Ecotype 10, one of the inferior accessions at the first harvest, ranked at or near the top for forage weight, total crude protein, and IVDMD at the second harvest. This difference may have reflected phenological differences because Ecotype 10 originated from the northern-most location and appeared to begin growing later in the spring and grew later into the summer than the other ecotypes.

Nodule mass varied significantly among the 11 ecotypes. Total acetylene reduction per plant was highest for Ecotypes 3, 4, and 5 at the first harvest (Table 5); Ecotypes 3 and 5 also had high specific

Table 4. Forage dry weight, crude protein content, total crude protein, and in vitro dry matter digestibility (IVDMD) of field grown plants of 11 sweetvetch accessions and alfalfa at 2 harvests. Each value represents the mean of 4 measurements[1].

Ecotype identification number	Forage weight (g plant^{-1})	Crude protein %	Total crude protein (g plant^{-1})	IVDMD (%)
Harvested 20–23 June 1984				
Sweetvetch:				
1	54 e	16.0a	8.6 d	54.8 ab
2	97 cde	15.9a	15.4 cd	48.8 bc
3	117 cd	16.6a	19.4 bc	50.0 bc
4	126 bc	17.3a	21.8 bc	51.7 b
5	168 b	15.6a	26.2 b	48.4 bc
6	120 bc	15.2a	18.2 c	52.4 b
7	122 bc	17.0a	20.7 bc	52.9 b
8	64 de	16.2a	10.4 d	49.9 bc
9	41 e	16.2a	6.6 e	52.4 b
10	69 de	12.9a	8.9 d	49.1 bc
11	64 de	16.0a	10.2 d	43.9 c
Mean	95	15.9	15.1	50.4
Alfalfa:	279 a	17.6a	49.1 a	61.8 a
Harvested 4–6 October 1984				
Sweetvetch:				
1	62 b	8.0 bc	5.0 b	35.7
2	82 b	10.2 a	8.3 b	40.2
3	83 b	7.8 bc	6.5 b	38.6
4	87 b	7.8 bc	6.8 b	28.8
5	68 b	9.4 ab	6.3 b	36.1
6	96 b	8.8 abc	8.4 b	30.2
7	115 b	5.4 d	7.2 b	37.6
8	85 b	8.1 bc	6.9 b	47.6
9	45 b	8.0 bc	3.6 b	28.8
10	135 b	7.4 c	10.0 b	49.3
11	57 b	10.3 a	5.9 b	41.3
Mean	83	8.3	6.8	37.7
Alfalfa:	1,167 a	10.7 a	124.8 a	41.2

[1]Means in the same column within a harvest that are followed by a different letter are significantly different by LSD at the 0.05 level.

Table 5. Nodule mass and acetylene reduction activity of field grown plants of 11 sweetvetch ecotypes at 2 harvests. Each value represents the mean of 12 measurements at the first harvest and 11 measurements at the second harvest[1].

Ecotype identification number	Nodule mass (mg plant^{-1})	Acetylene reduction activity (nmol C_2H_4) Total (plant^{-1} s^{-1})	Specific (g^{-1} nodule dry weight s^{-1})
	Harvested 20–23 June 1984		
1	0.33 bc	10.5 bc	24.2 bc
2	0.30 bc	6.1 c	13.9 c
3	0.61 ab	25.0 a	43.6 a
4	0.98 a	22.5 ab	18.6 bc
5	1.01 a	26.9 a	31.1 ab
6	0.61 ab	10.6 bc	19.7 bc
7	0.59 ab	8.3 c	15.6 bc
8	0.33 bc	10.8 bc	16.7 bc
9	0.10 c	4.4 c	18.9 bc
10	0.05 c	2.8 c	7.8 c
11	0.33 bc	8.6 c	21.4 bc
Mean	0.48	12.5	21.1
	Harvested 4–6 October 1984		
1	0.34 bc	0.0a	0.0a
2	0.11 c	0.0a	0.9a
3	0.51 b	0.0a	0.0a
4	0.14 c	0.1a	0.2a
5	0.26 bc	0.1a	0.1a
6	0.38 bc	0.1a	0.1a
7	0.28 bc	0.0a	0.0a
8	0.33 bc	0.2a	0.4a
9	0.23 bc	0.0a	0.1a
10	1.41 a	0.4a	0.3a
11	0.31 bc	0.0a	0.4a
Mean	0.39	0.1	0.2

[1]Means in the same column that are followed by a different letter are significantly different by LSD at the 0.05 level.

nodule activity. Acetylene reduction activity was extremely low in plants from the second harvest, and no significant differences were detected among the ecotypes. Nodule activity in sweetvetch apparently coincides with periods of most active growth. Nodule mass was generally lower for the second than the first harvest, and ranking of the ecotypes changed with harvests. Ecotype 10 had the lowest nodule mass at the first harvest, but exhibited the highest nodule mass at the second harvest. Nitrogen fixation characteristics of sweetvetch ecotypes could not be compared with those of alfalfa because none of the alfalfa plants in the field experiment were nodulated.

Other characteristics that may be important in breeding and selection programs include regrowth capability and rhizome development. Regrowth may be important in fall forage production, and rhizome development would be important in erosion control and resistance to grazing. Seven of the 11 sweetvetch ecotypes exhibited regrowth, whereas only Ecotypes 7, 9, and 10 showed any rhizome development (data not shown).

Field forage weight from Harvest 1 and seed production, probably the 2 most important economic variables examined in this study, were significantly and positively correlated ($r = 0.66$). Total crude protein and nodule mass from the field for Harvest 1 were significantly correlated with both forage and seed production from Harvest 1. Significant correlations were also found for the first field harvest between nodule mass and forage weight ($r = 0.89$) and between nodule mass for the first field harvest and seed production ($r = 0.62$). In addition, total acetylene reduction at the first field harvest was significantly correlated ($r = 0.73$) with forage weight at the first field harvest. These 3 correlations suggest that biological nitrogen fixation may have been important in the production of both forage and seed.

Relationships among Ecotypes

The results of the cluster analysis for the 11 sweetvetch ecotypes are shown in Figure 1. The cophenetic correlation coefficient of 0.78 indicated satisfactory agreement between the dendrogram and the resemblance matrix. Average taxonomic distance values for ecotype pairs ranged from 0.94 for Ecotypes 1 and 6 to 2.04 for Ecotypes 5 and 10 (Fig. 1). Ecotype 10, which represented the northernmost collection, was distinctly separated from the other 10 sweetvetch ecotypes with a taxonomic distance value of 1.62. Ecotypes 4 and 7, which originated from seed from Ecotype 5, were closely clustered near Ecotype 5 based on the 44 morphological and physiological attributes evaluated. This clustering of related collections suggests that this analysis procedure is a useful tool for identifying relationships among the sweetvetch collections. Although

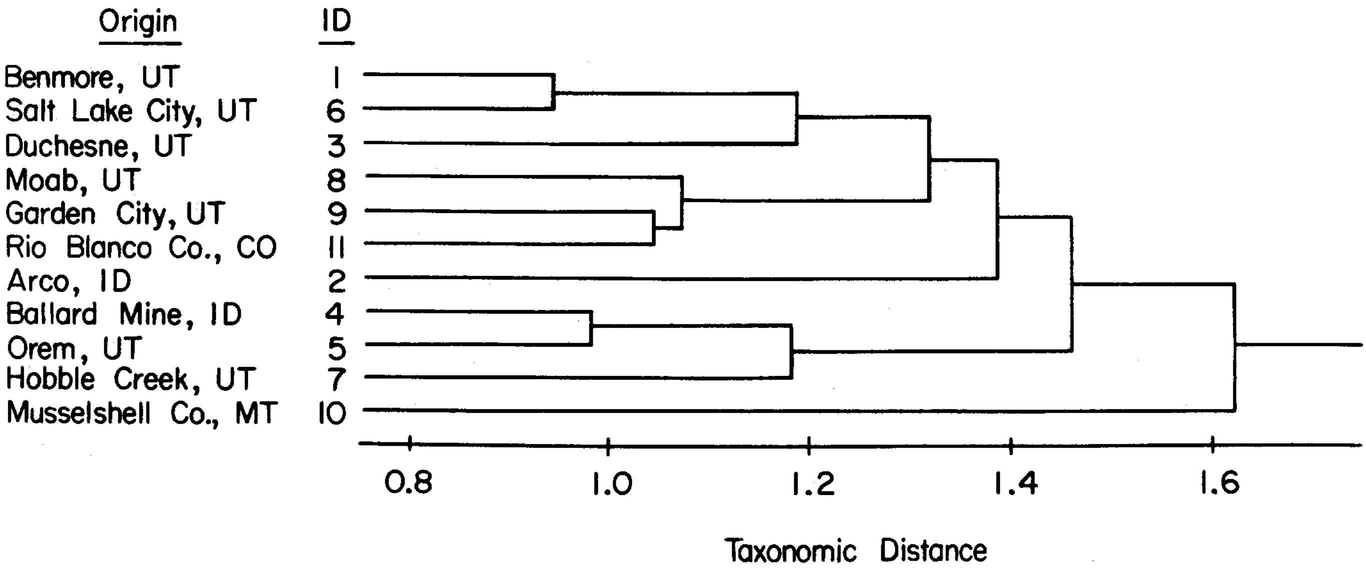

Fig. 1. *Cluster relationships of 11 sweetvetch ecotypes based on average taxonomic distance values computed from 44 morphological and physiological attributes measured in greenhouse and field experiments.*

Ecotypes 8 and 9 originated from sites that differed greatly in their precipitation (19 and 57 cm, respectively), their taxonomic distance values were nearly equal (1.07 and 1.05, respectively), suggesting that these ecotypes were genetically similar. Consequently, even though ecotypes differed in their taxonomic distance values, these differences were not always clearly related to specific characteristics of the collection site.

Conclusions

Sweetvetch produced substantial amounts of forage during early spring, but was apparently of little value for forage during the late-fall and winter because of its prostrate fall growth and limited forage production during this period. However, it may be possible to select sweetvetch cultivars with an ability to regrow during the fall. Acetylene reduction activities indicated that sweetvetch is capable of fixing nitrogen and would probably do well in nitrogen-limited environments. Considerable morphological and physiological variability was observed in the 11 sweetvetch ecotypes studied. Ecotype 5 excelled under the high water levels of the greenhouse line-source sprinkler system. Ecotype 3 was superior under the low water levels and may be best for planting on arid, nitrogen-limited sites. Ecotypes 7 exhibited the greatest rhizome development and may be valuable for stabilizing erodible sites. Ecotype 5, which exhibited superior seed yield, is a candidate for commerical seed production. Sufficient genetic diversity was present among the sweetvetch ecotypes to assure adaptation to a wide array of sites and to facilitate improvement through breeding and selection.

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