Evaluation of Potential Cover Crops for Inland Pacific Northwest Vineyards

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Numerous cover crops for orchards and vineyards have been evaluated, but many selections do not necessarily perform well in the cold, arid environment of the inland Northwest. A cover crop between vine rows can mitigate wind erosion and subsequent damage to young vines. However, low rainfall, gusty winds, and sandy soils that cause significant wind erosion problems can exacerbate cover crop establishment, and cold winters can limit cover crop survival. During 1998, 175 plant accessions were screened for performance as vineyard cover crops at Prosser, Washington. Assessed attributes included percent emergence, percent vegetative cover, stand duration, and plant height. Based on that assessment, seven domestic selections and four foreign *Medicago* species (medics) were identified for additional evaluation in a research trial in 1999. Additionally, seven accessions and two mixes of species that met the growth criteria and had commercial availability were evaluated in a commercial, drip-irrigated vineyard near Prosser in 1999. Vine water potential and soil moisture were determined in addition to the identical growth criteria from the 1998 study. Cover crop treatments did not lead to detectable water stress in the vines (midday y = -0.84 to -1.30 MPa). However, dry soil between vine rows due to precision drip irrigation inhibited germination and establishment of legumes; therefore, grasses had better emergence rates. Of the mixed species, a grass mix (Canada) composed of crested wheatgrass (*Agropyron cristatum* L.), pubescent wheatgrass (*Elytrigia intermedia* L.), and perennial rye (*Lolium perenne* L.; 40:40:20), depleted soil water the least and showed the least effect on vine water potential. Early season weeds were suppressed by most cover crop species; however, season-long suppression of weed growth was observed only for the Canada mix and crested wheatgrass cv. Fairway.

Key words: Cover crops, *Vitis vinifera* L., evaluation techniques, vineyards

Cover crop usage has increased in the past decade because of increased environmental awareness and organic practices. A number of studies have been conducted, but primarily in California [4,5,8,24], and thus do not necessarily apply to the inland Pacific Northwest, where cold winters, low rainfall, and gusty winds challenge cover crop survival.

Soil erosion due to frequent and intense winds (>8 $m \cdot s^{-1}$) is a significant concern in vineyards in the inland Pacific Northwest. The problem is exacerbated by low annual, primarily winter rainfall (<195 $mm \cdot yr^{-1}$; [26]), and very fine sandy loam or silt loam loess soil. In some seasons, 2 to 5 cm of topsoil can be relocated under these conditions; however, soil accumulates in areas with vegetative cover [7]. Cover crops can reduce both wind and water erosion [12].

Researchers have traditionally evaluated native plants [2,5,11] and agronomic crops like cereal rye (*Secale cereale* L.), oat (*Avena sativa* L.), barley (*Hordeum vulgare* L.), wheat (*Triticum aestivum* L.), and wheatgrass (*Agropyron cristatum* L.) as cover crops [5,10,23]. Cereal grains have been a predominant component of cover crop use because of their large biomass accumulation early in the growing season, preventing soil erosion [5,10,23]. Pasture legumes and grasses from semiarid climates have also been considered because of their adaptability to wide variation in environmental conditions [11,13,20,27]. Regional environmental conditions as well as microclimate conditions must be considered when evaluating cover crop species [5,16]. In addition to climate considerations, vineyard management strategies differ with region and grower and they range from frequent herbicide applications for clean cultivation to certified organic practices. Cover crop selections for certified organic vineyards may be different than for vineyards where herbicides are used because of rules of certification. In a traditionally managed vineyard, cover crops are grown between vine rows, with the area underneath the vine kept weed-free, usually with herbicide applications or cultivation. However, in an organic vineyard, cover crops are often allowed to grow underneath the vines, adding a level of competition for nutrients and water [9, 29]. In selecting a vineyard cover crop, one must account for vineyard management, local environmental conditions, and the grower's goals, such as reduction of pests and production costs and ease of mechanization.

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Due to the low annual rainfall in the inland Northwest, irrigation is required for commercial vineyard production. In the 1990s, many commercial winegrape growers have changed irrigation techniques from furrow to drip in an effort to conserve water and improve crop quality [25,31]. This shift in irrigation and interest in cover crop establishment necessitates the identification of drought-tolerant cover crops. Plants native to semiarid or arid regions are desirable; thus, forage legumes, grasses, and some forbes are ideal candidates for evaluation, based on their ability to grow successfully without supplemental irrigation and provide the soil cover required to mitigate wind erosion, if they can survive periodic low temperatures. Additionally, drought tolerant cover crops with adequate density early in the season can provide benefits such as weed suppression and reduced soil compaction [16].

The primary objective of this study was to screen 175 selections for their potential as cover crops in inland Pacific Northwest vineyards. The secondary objective was then to evaluate promising selections from the initial screening as potential cover crops in a commercial vineyard.

Materials and Methods

One hundred seventy-five entries were evaluated at Washington State University's Irrigated Agriculture Research and Extension Center (WSU-IAREC) in Prosser, WA (46°, 119.7°) during 1998 and 1999 (Table 1). Species previously shown to have promise as cover crops in arid areas were selected from the National Plant Germplasm System (NPGS) germplasm collections. Entries were defined as various ecotypes of different species and were labeled with an individual accession number. Entries included wild plant material and cultivated species. Cover crops commercially used in California vineyards, cover crops currently used in eastern Washington, and wild species commonly found in the arid inland Pacific Northwest ('native species') were also compared and evaluated.

Suitable cover crops for the inland Northwest might be expected to originate from areas with similar climates. Three databases were used to identify climates similar to that of the inland Northwest. The United States Department of Agriculture (USDA) plant hardiness zones delineate the world by average minimum temperatures [17], Nuttonson's agroclimate areas separate the United States into growing zones defined by the climactic characteristics that affect crop production [21,22], and Bailey's ecoregions [1] separate the world into regions of ecological similarity according to topography, climate, latitude, and longitude. The USDA-Agricultural Research Service (ARS) NPGS makes available to researchers a wide array of germplasm that has been collected and catalogued from around the world. The Germplasm Resources Information Network (GRIN), the NPGS database, was searched for species of cultivated and noncultivated plants originating from a given country. Each collection contains many accessions from various countries. Small amounts of seed were requested for screening.

Initial evaluation in 1998 was conducted in an experimental vineyard (*Vitis vinifera* L.) of Chardonnay, White Riesling, Cabernet Sauvignon, and Chenin blanc at WSU-IAREC. Vine spacing was 1.8 m between vines and 3.1 m between rows; vines were drip-irrigated. One hundred seventy-five entries were sown in 0.75 m^2 plots, arranged in randomized, complete blocks, and replicated five times. Forty-five seeds were sown to a prepared seedbed in a grid in each plot to facilitate emergence counts. The soil was a Warden silt loam (coarse-silty, mixed, mesic Xeric Haplocambid). All plots were hand-sown in early May over the course of two weeks (beginning day of year [DOY] 128), incorporated with a ringroller, and irrigated for two weeks under microsprinklers to initiate germination and aid establishment. All plots were weeded biweekly to minimize competition. Variables that could be measured objectively were used to the greatest practical extent. Attributes evaluated included percent of soil covered by vegetation (percent vegetative cover), aboveground biomass, plant height prior to flowering, phenology, and second-year regeneration [5]. Clovers and turfgrasses sown for "living mulches" have been assessed for date of emergence, stand density, and dominant weed species at cover crop harvest [20]. We chose a combination of these performance measures for screening potential cover crops [2,6,15,24].

Emergence was recorded within the grid of 45 seeds to calculate germination percentage. Changes in stand density and phenological stage were recorded for all entries. Those with an emergence that exceeded 45% were selected for further evaluation in the commercial trial. Stand density at 10 and 12 weeks after planting (WAP) was observed to indicate the change in number of live plants at 10 WAP from initial emergence values and 12 WAP from plants at 10 WAP. Many native seed sources have a natural variation in germination over a long period due to genetic variation and optimal environmental conditions [2]. Stand densities were monitored to observe this natural variation and plant adaptation to hot, dry summers. Stand density at 12 WAP was used to reduce the number of entries that would be evaluated in a commercial vineyard. Entries that decreased by more than 25% in stand density from 10 to 12 WAP were eliminated. Using germination performance and stand density as screening parameters, 33 entries were chosen for measurements of plant height (Table 2). The heights of three plants within each plot were measured in each replicate on DOY 204. Percent vegetative cover was analyzed using digital images of the plots for 15 of the 33 entries selected after the emergence and stand duration evaluations. Several entries were not included because too little aboveground material remained for valid measurements.

Plots from the 1998 screening trial were left undisturbed during the winter and assessed for regeneration in April 1999. Stand duration was defined as the presence or absence of cover crops in individual plots. Based on rankings for emergence, stand duration, vegetative cover, and plant height, seven entries were chosen for a commercial trial with greater acreage the following year (1999; Table 3). Two industry standards (cereal rye and crested wheatgrass cv. Fairway) were chosen for comparison. Two cultivars of *Medicago lupulina* L. (cv. George and cv. Dr. B) were added to the 1999 trial to assess performance of pasture legumes, totaling 11 entries. Unfortunately, large quantities of the foreign medics and *Medicago lupulina* L. cv. Dr. B were not available; thus, only commercially available seeds of these 11 entries were planted in the commercial trial (Table 3).

Table 1 Entries used in 1998 cover crop trial in Prosser, WA. Values are means of five replicates. PI numbers indicate the accession number within the NPGS Plant Introduction system. Different accessions represent various ecotypes within a plant species.

Entry	Common name	PI number or cultivar	Geographic origin	Emergence (%)
Achillea millefolium	White yarrow		USA, inland Pacific Northwest	10.2
Agropyron cristatum	Crested wheatgrass		USA	4.0
Aster subspicatus			USA, inland Northwest	12.0
Astragalus cicer	Astragalus	PI 440143	Kazakhstan	20.9
Astragalus ponticus	Astragalus	PI 440147	Kazakhstan	9.8
Astragalus-big	Astragalus	PI 602380	USA, inland Northwest	0.0
Astragalus-small	Astragalus	PI 515984	USA, inland Northwest	2.2
Balsamorhiza sagittata	Arrowleaf Balsamroot		USA, inland Northwest	0.4
Balsamorhiza hookeri	Arrowleaf Balsamroot		USA, inland Northwest	3.1
Calochortus macrocarpus	Mariposa lily		USA, inland Northwest	24.0
Dalea candida	White prairie clover	PI 478834	USA, Northern Plains	11.2
Dalea purpurea	Purple prairie clover	PI 599339	USA, Northern Plains	11.1
Dalea villosa		PI 215266	USA, Northern Plains	2.2
Delphinium occidentalis	Larkspur		USA, inland Northwest	45.8
Echinacea purpurea	Purple cornflower		USA, inland Northwest	0.9
Fritillaria pudica	Yellow bells		USA, inland Northwest	15.6
Gaillardia aristata	Blanket flower		USA, inland Northwest	1.8
Hedysarum gmelinii		PI 577677	Russian Federation	1.3
Liatris, sp.	Spiked gayfeather		USA, inland Northwest	0.0
Linum perenne	Lewis blue flax		USA, inland Northwest	60.0
Linum perenne	Scarlet flax		USA, inland Northwest	1.6
Lomatium macrocarpum	Bigseed desert parsley		USA, inland Northwest	2.7
Lomatium triternatum	Nineleaf desert parsley		USA, inland Northwest	2.2
Lotus corniculatus	Birdsfoot trefoil	W6 19779	Mongolia	28.9
Lotus corniculatus	Birdsfoot trefoil	PI 440482	Kazakhstan	8.9
Lotus corniculatus	Birdsfoot trefoil	PI 440483	Kazakhstan	25.3
Lotus corniculatus	Birdsfoot trefoil	PI 440485	Kazakhstan	13.8
Lotus glaber	Narrowleaf trefoil	PI 308035	Slovakia	8.0
Lotus glaber	Narrowleaf trefoil	PI 310412	USSR	10.7
Lotus glaber	Narrowleaf trefoil	PI 440486	Kazakhstan	6.7
Lotus glaber	Narrowleaf trefoil	PI 577300	Denmark	17.3
Lupinus laxiflorus	Silky lupine		USA, inland Northwest	29.8
Lupinus sericeus	Silky lupine		USA, inland Pacific Northwest	2.0
Medicago littoralis	Strand medic	PI 577328	Czech Republic	25.8
Medicago littoralis	Strand medic	PI 537178	France	48.4
Medicago littoralis	Strand medic	PI 537180	France	30.7
Medicago lupulina	Black medic	Dr. B.	USA, Montana	3.1
Medicago lupulina	Black medic	George	USA, Montana	19.1
Medicago lupulina	Black medic	PI 207497	Afghanistan	53.3
Medicago lupulina	*Black medic*	*PI 211605*	*Afghanistan*	*12.9*
Medicago lupulina	Black medic	PI 221939	Afghanistan	50.7
Medicago lupulina	Black medic	PI 222065	Afghanistan	44.9
Medicago lupulina	Black medic	PI 222195	Afghanistan	30.7
Medicago lupulina	Black medic	PI 222196	Afghanistan	33.3
Medicago lupulina	Black medic	PI 222197	Afghanistan	46.2
Medicago lupulina	Black medic	PI 223786	Afghanistan	34.3
Medicago lupulina	Black medic	PI 269926	Pakistan	53.8
Medicago lupulina	Black medic	PI 314455	Georgia	49.8
Medicago lupulina	Black medic	PI 540431	Pakistan	31.1
Medicago minima		PI 314456	Georgia	29.8
Medicago minima		PI 538999	Russian Federation	36.9
Medicago orbicularis	Button medic	PI 566870	Romania	31.6
Medicago orbicularis	Button medic	W6 5203	Ukraine	30.2
Medicago orbicularis	Button medic	W6 8294	Tajikastan	35.1
Medicago orbicularis	Button medic	PI 220021	Afghanistan	21.8
Medicago orbicularis	Button medic	PI 219599	Romania	64.5
Medicago polymorpha	Burr medic	Carpet	USA, California	70.2
Medicago polymorpha	Burr medic	Santiago	USA, California	10.7

Table 1 continued

Entry	Common name	PI number or cultivar	Geographic origin	Emergence (%)
Medicago polymorpha	Burr medic	W6 5355	Romania	42.9
Medicago polymorpha	Burr medic	W6 5356	Romania	36.9
Medicago polymorpha	Burr medic	W6 5572	Romania	38.7
Medicago polymorpha	Burr medic	PI 478439	Bolivia	54.7
Medicago polymorpha	Burr medic	PI 478466	Bolivia	27.2
Medicago polymorpha	Burr medic	PI 478530	Peru	55.1
Medicago polymorpha	Burr medic	PI 566878	Georgia	19.1
Medicago polymorpha	Burr medic	PI 577413	Romania	25.8
Medicago polymorpha	Burr medic	PI 577437	Pakistan	21.8
Medicago rigidula		W6 8307	Uzbekistan	39.1
Medicago rigidula		W6 8308	Uzbekistan	48.4
Medicago rigidula		W6 8310	Tajikistan	44.0
Medicago rigidula		W6 8311	Uzbekistan	38.7
Medicago rigidula		PI 495567	USSR	51.1
Medicago rigidula		PI 539008	Turkmenistan	39.5
Medicago rigidula		W6 8309	Uzbekistan	10.7
Medicago sativa ssp. falcata	Alfalfa	PI 440531	Kazakhstan	29.8
Medicago sativa ssp. falcata	Alfalfa	PI 440537	Kazakhstan	33.1
Medicago sativa ssp. falcata	Alfalfa	PI 440538	Kazakhstan	43.6
Medicago sativa ssp. falcata	Alfalfa	PI 440539	Kazakhstan	34.7
Medicago sativa ssp. falcata	Alfalfa	PI 440540	Kazakhstan	43.6
Medicago sativa ssp. falcata	Alfalfa	PI 499548	China	33.8
Medicago sativa ssp. falcata	Alfalfa	PI 499663	China	42.3
Medicago sativa ssp. falcata	Alfalfa	PI 499664	China	29.3
Medicago sativa ssp. falcata	Alfalfa	PI 499666	China	24.0
Medicago sativa ssp. falcata	Alfalfa	PI 538984	Kazakhstan	19.9
Medicago sativa ssp. falcata	Alfalfa	PI 538985	Kazakhstan	52.4
Medicago sativa ssp. falcata	Alfalfa	PI 538989	Russian Federation	49.8
Medicago scutellata	Snail medic	PI 487392	Sweden	15.1
Medicago scutellata	Snail medic	Jaime	USA, Montana	0.4
Medicago truncatula	Barrel medic	Parabinga	USA, California	8.9
Medicago truncatula	Barrel medic	PI 566889	Turkey	22.8
Medicago truncatula	Barrel medic	PI 577608	France	28.7
Medicago truncatula	Barrel medic	PI 577611	Germany	21.1
Medicago truncatula	Barrel medic	PI 577635	France	17.8
Medicago truncatula	Barrel medic	PI 577642	Germany	30.7
Melilotus albus	Sweet medic	PI 602055	USA, Nebraska	19.5
Melilotus officinalis	Sweet clover	PI 602057	USA, Colorado	29.8
Melilotus officinalis	Sweet clover	PI 552552	USA, Nebraska	4.4
Oenothera speciosus	Evening primrose		USA, Inland Pacific Northwest	35.1
Oenothera lamarckiana	Mexican evening primrose		USA, inland Pacific Northwest	0.0
Onobrychis transcaucasia	'Renumex 15'	PI 403967	Russian Federation	28.0
Onobrychis viciifolia	'Hybrid 15'	PI 600767	USA, New Mexico	0.9
Oryzopsis hymenoides	Nez par Indian ricegrass		USA, Inland Northwest	68.9
Penstemon palmeri	Palmer's penstemon		Russian Federation	56.4
Penstemon strictus	Rocky Mountain penstemon		USA, inland Pacific Northwest	53.3
Poa ampla	Big bluegrass		USA, inland Pacific Northwest	4.4
Poa sandbergii	Sandberg's bluegrass		USA, inland Pacific Northwest	47.1
Pseudoroegneria spicatum	Bluebunch wheatgrass	Secar	USA, inland Pacific Northwest	2.7
Ratibida columnaris	Mexican hat coneflower		USA, inland Pacific Northwest	19.6
Secale cereale	Cereal rye 'Wheeler'		USA	54.7
Securigera varia		PI 278698	USA, Iowa	18.7
Securigera varia		PI 326324	USSR	10.2
Securigera varia		PI 340779	USA, Northern Plains	16.4
Securigera varia		PI 343944	Latvia	0.9
Sphaeralcea munroana	Globe mallow	Munro's	USA, inland Pacific Northwest	7.1
Trifolium hirtum	Rose clover	Monte Frio	USA, California	52.9
Trifolium hirtum	Rose clover	PI 591664	Bulgaria	54.7
Trifolium hirtum	Rose clover	PI 591665	Bulgaria	4.9

Table 1 continued

Entry	Common name	PI number or cultivar	Geographic origin	Emergence (%)
Trifolium incarnatum	Crimson clover	PI 495567	USA, California	8.9
Trifolium incarnatum	Crimson clover	PI 251562	Yugoslavia	2.7
Trifolium incarnatum	Crimson clover	PI 251563	Yugoslavia	10.8
Trifolium incarnatum	Crimson clover	PI 255892	Poland	10.9
Trifolium incarnatum	Crimson clover	PI 422487	Germany	18.3
Trifolium incarnatum	Crimson clover	PI 442556	Belgium	10.7
Trifolium incarnatum	Crimson clover	PI 561944	USA, California	16.0
Trifolium pratense	Red clover	PI 207521	Afghanistan	38.0
Trifolium pratense	Red clover	PI 268429	Afghanistan	33.3
Trifolium pratense	Red clover	PI 314338	Uzbekistan	45.3
Trifolium pratense	Red clover	PI 314339	Uzbekistan	31.4
Trifolium pratense	Red clover	PI 314340	Uzbekistan	25.3
Trifolium pratense	Red clover	PI 314341	Uzbekistan	11.6
Trifolium pratense	Red clover	PI 314487	Georgia	18.7
Trifolium pratense	Red clover	PI 314757	Kazakhstan	8.4
Trifolium pratense	Red clover	PI 314758	Kazakhstan	9.9
Trifolium pratense	Red clover	PI 314759	Kazakhstan	16.9
Trifolium pratense	Red clover	PI 314760	Kazakhstan	27.6
Trifolium pratense	Red clover	PI 314761	Kazakhstan	6.2
Trifolium pratense	Red clover	PI 388631	Uzbekistan	12.0
Trifolium pratense	Red clover	PI 440741	Kazakhstan	21.3
Trifolium pratense	Red clover	PI 440742	Kazakhstan	6.7
Trifolium pratense	Red clover	PI 440743	Kazakhstan	16.4
Trifolium pratense	Red clover	PI 440744	Kazakhstan	13.8
Trifolium repens	White clover	PI 108722	Kazakhstan	24.4
Trifolium repens	White clover	PI 115416	Kazakhstan	23.1
Trifolium repens	White clover	PI 197870	Argentina	26.7
Trifolium repens	White clover	PI 253323	Slovenia	16.6
Trifolium repens	White clover	PI 314763	Kazakhstan	27.6
Trifolium repens	White clover	PI 440747	Kazakhstan	40.0
Trifolium repens	White clover		USA, California	28.3
Trifolium subterranean	Sub-clover	Koala	Australia	6.7
Trifolium subterraneum	Sub-clover	PI 378136	United Kingdom	16.9
Trifolium subterraneum	Sub-clover	PI 493263	France	35.9
Trifolium subterraneum	Sub-clover	PI 493264	France	19.1
Trifolium subterraneum	Sub-clover	PI 493265	France	36.9
Trifolium subterraneum	Sub-clover	PI 535765	Turkey	24.9
Vicia americana	Vetch		USA, inland Pacific Northwest	30.7
Vicia americana	Vetch	PI 452486	Canada	4.9
Vicia cracca		PI 352708	USA, inland Pacific Northwest	40.5
Vicia dumetorum		PI 494749	Romania	1.3
Vicia ervilia		PI 205289	Turkey	47.9
Vicia graminea		PI 414368	Uruguay	62.7
Vicia grandiflora		PI 602377	USA	50.7
Vicia hirsuta		PI 422499	Germany	33.3
Vicia hybrida		W6 17061	USA, Northern Plains	5.6
Vicia hyrcanica		PI 561419	Uzbekistan	20.1
Vicia lathyroides		PI 422500	Germany	3.8
Vicia lutea		PI 249880	Greece	22.1
Vicia michauxii		PI 561420	Uzbekistan	73.3
Vicia monantha		PI 388818	Morocco	50.2
Vicia pannonica		PI 220888	Belgium	3.5
Vicia peregrina		PI 393824	Uzbekistan	66.8
Vicia pisiformis		PI 358868	Turkey	60.9
Vicia sativa	Common vetch	PI 204643	Turkey	18.7
Vicia sylvatica		PI 442562	Belgium	61.1
Vicia tetrasperma		PI 420173	France	2.7
Vicia villosa	Hairy vetch	PI 317447	Afghanistan	1.3

Table 2 Emergence and changes in stand counts for the top-emerging entries in 1998 research trial at Prosser, WA. Negative values denote reduction in stand at 10 weeks after planting (WAP) from initial emergence; 12 WAP values were compared to stand counts at 10 WAP.

Accession	PI number or cultivar	Emergence (%) DOY 170	Change in stand (%) 10 WAP	Change in stand (%) 12 WAP	Vegetative cover (%) 13 WAP	Plant height (cm) 10 WAP
Medicago truncatula	Parabinga	56.4[abcdef†]	-32.3	-13.3	12.0[abcd]	24.3[cdefg]
Medicago polymorpha	Santiago	53.3[abcdefg]	-6.7	-35.6	———	18.2[fghij]
Secale cereale		70.2[ab]	-15.3	-16.4	17.6[a]	17.5[ghijk]
Agropyron cristatum	Fairway	54.7[abcdefg]	5.6	-8.8	8.0[bcd]	48.9[a]
Linum perenne	Scarlet flax	60.0[abcde]	-10.6	-38.9	8.0[bcd]	30.2[bcd]
Medicago littoralis	PI 537180	48.4[cdefgh]	-3.0	-13.9	11.5[abcd]	20.9[efgh]
Medicago lupulina	Dr. B	45.8[defgh]	3.8	0.5	15.2[ab]	4.7[l]
Medicago lupulina	George	44.4[efgh]	-5.3	4.0	12.8[abcd]	4.8[l]
Medicago lupulina	PI 211605	53.3[abcdefg]	-12.3	-19.8	———	13.7[hijk]
Medicago lupulina	PI 222065	50.7[bcdefgh]	3.2	-14.9	———	14.6[hijk]
Medicago lupulina	PI 314455	53.8[abcdefg]	-5.9	7.1	———	18.5[defg]
Medicago orbicularis	PI 219599	36.9[fgh]	-15.5	17.3	6.8[cd]	———
Medicago orbicularis	PI 220021	35.1[gh]	-0.6	-2.2	10.4[abcd]	———
Medicago orbicularis	W6 5203	31.6[h]	-7.6	-30.4	10.5[abcd]	21.3[efgh]
Medicago polymorpha	W6 5355	64.4[abcde]	-11.9	-36.1	———	23.1[defg]
Medicago polymorpha	PI 478439	54.7[abcdefg]	-0.1	-33.3	———	26.8[cde]
Medicago polymorpha	PI 566878	55.1[abcdefg]	-14.8	-2.6	———	9.9[kl]
Medicago rigidula	PI 539008	51.1[bcdefgh]	8.0	-10.7	14.4[ab]	10.5[jkl]
Medicago rigidula	PI 495567	38.7[efgh]	10.0	-5.8	12.0[abcd]	11.1[ijkl]
Medicago rigidula	W6 8309	39.6[efgh]	2.7	-10.7	14.4[ab]	10.1[ijkl]
Medicago sativa ssp. falcata	PI 538989	52.4[abcdefgh]	9.6	-6.2	———	35.6[b]
Medicago scutellata	PI 487392	49.8[bcdefgh]	190.8	-22.4	13.6[abc]	26.3[cde]
Trifolium hirtum	Monte frio	52.9[abcdefg]	2.5	-5.4	8.0[bcd]	16.8[ghijk]
Trifolium incarnatum	PI 495568	54.7[abcdefg]	15.3	-10.8	———	31.3[bc]
Trifolium pratense	PI 440743	45.3[defgh]	-3.4	-12.5	———	———
Trifolium subterraneum	Koala	68.9[abc]	-0.3	-18.1	5.5[d]	4.9[l]
Vicia hirsuta	PI 422499	62.7[abcde]	-42.1	-21.1	———	11.1[ijkl]
Vicia hybrida	W6 17061	50.7[bcdefgh]	-29.5	-61.9	———	17.1[ghijk]
Vicia pannonica	PI 220888	73.3[a]	-15.1	-55.5	———	16.9[ghijk]
Vicia peregrina	PI 393824	50.4[bcdefgh]	-27.8	-60.9	———	21.5[efgh]
Vicia sativa	PI 204643	65.8[abcd]	-16.1	-81.3	———	25.6[cdef]
Vicia sylvatica	PI 442562	60.9[abcde]	-12.5	-82.2	———	11.2[ijkl]
Vicia villosa	PI 317447	61.2[abcde]	-4.7	-55.1	———	25.6[cdef]

†Means with the same letter are not significantly different (Fisher's LSD, $p < 0.05$).

In 1999, seven single-species cover crops and two interspecific mixes (Canada mix and Fescue mix) selected from the previous year (Table 3) were sown in a commercial vineyard of four-year-old, own-rooted *Vitis vinifera* cv. Merlot trained to a spur-pruned, bilateral cordon system (Alderridge Vineyards, Alderdale, WA [45°, 119.8°]). Santiago burr medic was substituted for Parabinga barrel medic, which was unavailable from the seed company. Vine spacing was 1.2 m between vines and 2.7 m between rows; vines were drip-irrigated. The soil was a Prosser-Bakeoven complex (Prosser: sandy-loam, coarse-loamy, mixed, superactive, mesic Xeric Haplocambid; Bakeoven: cobbly-loam, loamy-skeletal, mixed, superactive, mesic Lithic Haploxeroll). Seedbeds were prepared by disking between rows. Legumes were preinoculated with the appropriate strain of rhizobia inoculum and scarified with sandpaper before planting. Seed was drilled 5 cm deep (Tye Drill, Duluth, GA) in December 1998 to take advantage of precipitation from winter rains. Plots were 878 m^2 (three rows, 1.5 m x 195 m) replicated four times in randomized complete blocks. Resident vegetation (weeds) was used as a control. The vineyard was mown periodically to maintain all cover crops at 8 cm. Mower height was above tops of prostrate-growing selections and did not appear to affect them. The only water added between vine rows was by precipitation (9.13 mm between March and September). No fertilizers or herbicides were applied to cover crop treatments during the experiment.

Soil water content was estimated from weekly measurements by a capacitance method (Troxler Sentry 200AP, Providence, RI), using commercial software to convert the dielectric constant to equivalent measures (mm/m) of water (PRISM, Irrigation Scheduling Methods, Malaga, WA). Measurements were recorded at 0.3 and 0.6 m, using access tubes installed between the vine rows, in five of the nine entries (cereal rye, Koala subterranean clover, Santiago burr medic, Canada mix, and control).

Table 3 Cover crops selected from large evaluation trial in 1998. Entries commercially available were planted in a commercial vineyard (Alderridge Vineyard, Corus Brands, Inc.), Alderdale, WA, 1999.

Scientific name	PI number or common name
Secale cereale	Cereal rye[a]
Agropyron cristatum	Fairway crested wheatgrass[a]
Agropyron cristatum *Elytrigia intermedia* *Lolium perenne*	Canada mix[b]
Festuca ovina duriuscula *Festuca ovina* *Festuca arundinacea*	Fescue mix[a,b]
Poa ampla	Sherman big bluegrass[a,b]
Medicago lupulina	George black medic[a]
Medicago lupulina	Dr. B black medic
Medicago polymorpha	Santiago burr medic or burclover[a,c]
Trifolium subterraneum	Koala sub-clover[a]
Trifolium hirtum	Monte Frio rose clover[a]
Medicago truncatula	Parabinga barrel medic
Medicago rigidula	N/A, PI # W6 8309
Medicago orbicularis	Button medic, PI # W6 5203
Medicago scutellata	Snail medic, PI # 487392
Medicago littoralis	Strand medic, PI # 537180

[a]Commercially available seed.
[b]Added in 1999 to commercial trial; not evaluated in initial 1998 trial.
[c]Santiago was substituted for Parabinga in the 1999 commercial trial due to seed unavailability.

Vine water status was assessed four times during the growing season (DOY 196, 210, 224, 238) by measuring xylem water potential (ψ_s) on current year's growth with a pressure chamber (PMS Instruments, Corvallis, OR), following the method of Naor and Wample [18]. Forty vines were measured each sampling period; one vine in each treatment was randomly chosen. These vines were flanked on either side by the specific cover crop treatment. Measurements were taken around solar noon on each sampling date.

Performance variables measured for all cover crops in the 1999 study included emergence, phenological stage, plant height, vegetative cover, biomass, and leaf area. Emergence was assessed visually on 24 April (DOY 114). Phenological stage was assessed visually on 15 June (DOY 166) by categorizing flowering and seed maturation stages where applicable. Plant height was measured (three plants per plot) five times from 1 April (DOY 91) to mowing on 1 June (DOY 152). Vegetative cover was assessed using digital image analysis [19,28,30]. A 0.25 m^2 quadrat was placed in the middle of each cover crop plot and a digital image was taken with a digital camera using a flash to create uniform backlighting. Measurements were taken on overcast days to eliminate shadows. Images were transferred to a personal computer, and percent cover was visually assessed before analyzing the images with a commercial software package, Sigma Scan Pro (version 5.0; SPSS, Chicago, IL).

Leaf area and aboveground biomass were measured three times during the growing season. Before drying, weeds and cover crops were separated and their respective leaf areas measured (LI-3000, LI-COR, Lincoln, NE). Aboveground biomass was collected within a 0.25 m^2 quadrat placed randomly in each row (n=120). In cover crop blocks, weeds and cover crop plants were separated before drying. Plants were oven-dried at 60°C for 72 hr then weighed.

All data were analyzed using general linear models performed using Minitab Statistical Software (Minitab, Inc., State College, PA). Separation of treatment differences was performed using Fisher's protected LSD (SAS Institute, Cary, NC).

Results and Discussion

Initial screening—1998. Among 175 accessions, emergence varied from zero (*Oenothera speciosus)* to 73.3% (*Vicia michauxii*; Table 1). Many of the native species emerged well, but died back in the high temperatures of late June and July (Figure 1). Thirty-two entries exceeded 45% emergence by 5 WAP, but some of those species died back soon after stand counts were recorded, probably due to lack of irrigation. Increases within individual stands at 10 WAP were observed in Dr. B black medic, *Medicago lupulina* L. (PI 222065), *M. rigidula* L. (PI 539008, PI 495567, W6 8309), *M. scutellata* L., crimson clover (*Trifolium incarnatum* L.), and Monte Frio rose clover (*Trifolium hirtum* L.), suggesting that they were slow to emerge, but established well in terms of survivability over the early part of the

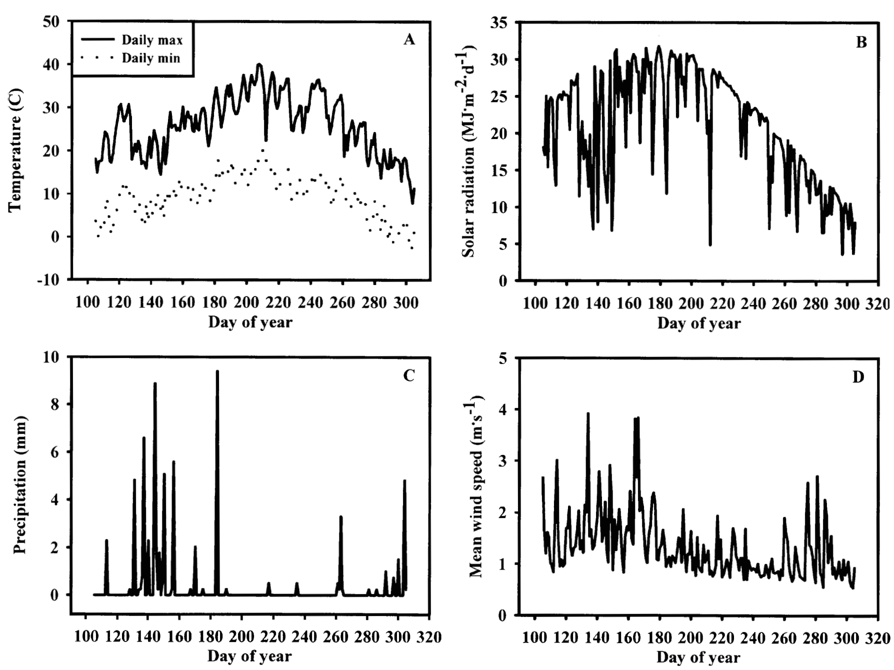

Figure 1 Daily air temperatures (**A**), total solar radiation (**B**), precipitation (**C**), and mean wind velocity (**D**) recorded by the Public Agricultural Weather System weather unit at WSU-IAREC, Prosser, WA during the 1998 growing season.

growing season. Stand density typically decreased between 10 WAP and 12 WAP for many entries (Table 2). This may have been due to the winter annual nature of these entries or to the fact that the Columbia basin was 60% drier than average for spring 1998 (250 mm avg. year^{-1}; 150 mm between November 1997 and May 1998) [26]. In contrast to most plants, black medic (*M. lupulina* L.), *M. orbicularis* L. (PI 219599), and both George and Dr. B black medics increased in plant counts between 10 and 12 WAP (Table 2). We assumed that the increase was due to delayed germination and hard seed coats associated with these legumes.

Vegetative cover ranged from 5.5 to 17.6% at 13 WAP (Table 2). Legumes like *T. subterraneum* cv. Koala had poor coverage, but good emergence, possibly due to smaller plant size because of low rainfall (Figure 2). In addition, root systems of these legumes were very shallow as indicated by soil water content data. In contrast, the medic *M. polymorpha* L. cv. Parabinga had very good branching and vegetative cover (Table 2). Cereal rye had the highest vegetative cover (17.6%) because of extensive tillering, which increased plant density.

Crested wheatgrass (*Agropyron cristatum* L.) was over 48 cm tall by 10 WAP, while Koala sub-clover, a prostrate species, was only 4.9 cm (Table 2). A maximum plant height of 25 cm was used as a criterion for selecting potential entries for the ease of movement through the vineyard by workers and equipment. In addition, plants in which workers or equipment often were tangled were no longer considered. Consequently, all *Vicia* species were discarded because of their tangled growth habit and high potential for spreading throughout the vineyard as a noxious weed [14]. Those accessions with height measurements above 25 cm and low vegetative cover (<10%), like *Linum perenne* L. (scarlet flax), were considered inadequate as single-species cover crops, but should be evaluated for suitability as a mixed-species cover.

Few of the entries in the 1998 trial regenerated in 1999 (Dr. B, George, crested wheatgrass, *M. rigidula*, *M. sativa spp. falcata*), despite having produced seed (data not shown). Legumes produce a high amount of hard seed; perhaps some scarification was needed to initiate germination. The most effective self-seeding plants were cereal rye and crested wheatgrass.

Of the 11 entries chosen for commercial vineyard planting trials in 1999, many were cultivated species (Table 3). Among them, crested wheatgrass emerged consistently across all plots by 10 WAP (48.9 to 60.0%; ± 7.14%). Cereal rye had the highest emergence (70.2%), although it showed increased variation across blocks (± 15.55%) (Table 2). Four of the 11 entries were cool-climate medics of foreign origin (France, Sweden, Ukraine) that tended to produce the greatest cover and emerged best among the 175 entries.

Commercial vineyard trial—1999. Compared to 1998, cover crops had improved emergence in the 1999 commercial vineyard trial. Cover crop emergence varied widely among plots, from 23.8 (George black medic) to 85.6% (Fairway crested wheatgrass; Table 4). Fairway crested wheatgrass, cereal rye, and the Canada mix emerged best, at 86%, 76%, and 63%, respectively (Table 4). Early growth of the Canada mix was dominated by perennial ryegrass (*Lolium perenne* L.), an early-germinating species. Legumes generally emerged poorly (Table 4). Poor stand establishment may have been due to seeding method. All seeds were drilled to 5 cm, which is deep for most legumes [3]. Environmental conditions contributed to the poor establishment of legumes, particularly lower-than-average winter rainfall (<10 mm, March through September; 195 mm avg.; Figure 1) [26] and cool spring temperatures (11°C [high], January 1 through April 1; Figure 2). Further evaluation of species-specific culture to establish legumes as cover crops is needed.

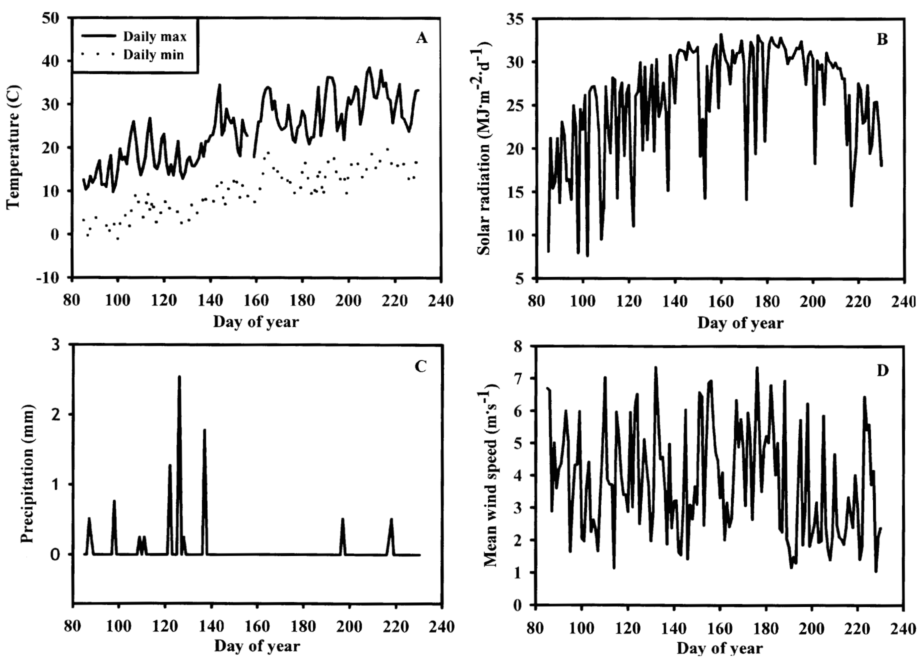

Figure 2 Daily air temperatures (**A**), total solar radiation (**B**), precipitation (**C**), and mean wind velocity (**D**) recorded by the Public Agricultural Weather System weather unit at Alderdale, WA during the 1999 growing season.

Phenological stages of cover crops in the commercial trial were assessed to determine anthesis on 15 June 1999 (DOY 166; Table 4). As expected, most species were in bloom. George black medic had advanced to seed development, indicated by the black seed coat on partially or fully dehisced seed bodies. Koala sub-clover was flowering and the tendril by which this species buries it seed was present at the time of assessment. Conversely, Sherman big bluegrass was vegetative and did not flower until early August (DOY 222). All legumes flowered before grasses, reflecting earlier anthesis and suggesting that legumes died back earlier than grasses, possibly offering less competition with vines for nutrients and water.

The dominant resident species within control blocks varied during the season.

Table 4 Establishment and growth of nine cover crop candidates and resident vegetation in 1999 commercial vineyard trial at Alderdale, WA.

Species	Seeding rate (kg/ha)	Emergence (%) DOY 72	Plant height (cm) DOY 152	Vegetative cover (%) DOY 197	Phenological stage DOY 166
Cereal rye	14.6	76.3 [b†]	56.3[a]	32.0[ab]	80-90% bloom, extensive tillering
Fairway crested wheatgrass	22.4	85.6[a]	26.3 [cd]	28.6[abc]	20% bloom, extensive tillering
Canada mix[a]	22.4	62.5 [c]	34.9 [bc]	28.2[abc]	30-40% bloom
Fescue mix[b]	22.4	40.0 [de]	34.8 [bc]	10.2 [d]	20-30% bloom
Sherman big bluegrass	22.4	62.5 [c]	24.2 [d]	16.6 [cd]	Vegetative
George black medic	11.2	23.8 [f]	4.8 [e]	9.3 [d]	75-85% bloom, seed pods present and maturing
Santiago burr medic	28.0	42.5 [d]	8.9 [e]	19.9 [bcd]	100% bloom, seed maturing, plants entering dormancy
Koala sub-clover	28.0	28.8 [f]	4.2 [e]	17.2 [cd]	85% bloom, seeds set into ground
Monte Frio rose clover	28.0	31.3 [ef]	7.8 [e]	10.8 [d]	90-95% bloom, seed heads present
Control	N/A	N/A	37.8 [b]	36.6[a]	N/A

†Means with the same letter are not significantly different (Fisher's LSD, $p < 0.05$).
[a]Canada mix consists of Fairway crested wheatgrass, pubescent wheatgrass, and perennial ryegrass.
[b]Fescue mix consists of tall, hard, and sheep fescues.

Resident vegetation was defined as introduced weedy species, and included coast fiddleneck (*Amsinckia intermedia* Fisch. & Mey), cutleaf nightshade (*Solanum triflorum* Nutt.), flixweed (*Descuraninia sophia* L.), wavyleaf thistle (*Cirsium undulatum* L. Nutt. Spreng.), and downy brome (*Bromus tectorum* L.). In May and June, coast fiddleneck and flixweed dominated the control plots. In the trial blocks of Santiago burr medic, Fairway crested wheatgrass, and cereal rye, there was a reduction in the resident vegetation biomass (Figure 3).

Domination of individual weed species within control plots varied at specific times during the growing season. Due to the variation in dominant weed species, average plant height in control plots varied. Thus, multiple species were measured to determine an average plant height across control plots. Although plots were mowed three times, the only cover crop entries to be affected were cereal rye and to a minor extent, crested wheatgrass. Thus, several of these species could be useful where growers wish to reduce mowing frequency and labor cost. Grass species generally were tallest (Table 4) and would require more frequent mowing. Legumes were significantly shorter than grasses ($p < 0.001$).

Only four of the nine entries covered more than 25% of the soil by mid-July. Resident vegetation had the highest vegetative cover (37%), followed by cereal rye (32%), and Canada mix (29%; Table 4). Santiago burr medic achieved the highest cover of the legumes because of its prostrate, branching growth habit. Emergence was not as high for the burr medic as for some of the grasses, but it surpassed all legumes in vegetative cover (Table 4).

Good vegetative cover by the grass species and the burr medic restricted weed establishment. We believe a mix of the Santiago medic and the crested wheatgrass could further reduce this weed biomass because of the prostrate growth habit of the medic and the high biomass production of the crested wheatgrass, although we did not test this specific combination. Santiago medic has early emergence with high amounts of vegetative cover, while crested wheatgrass has later emergence

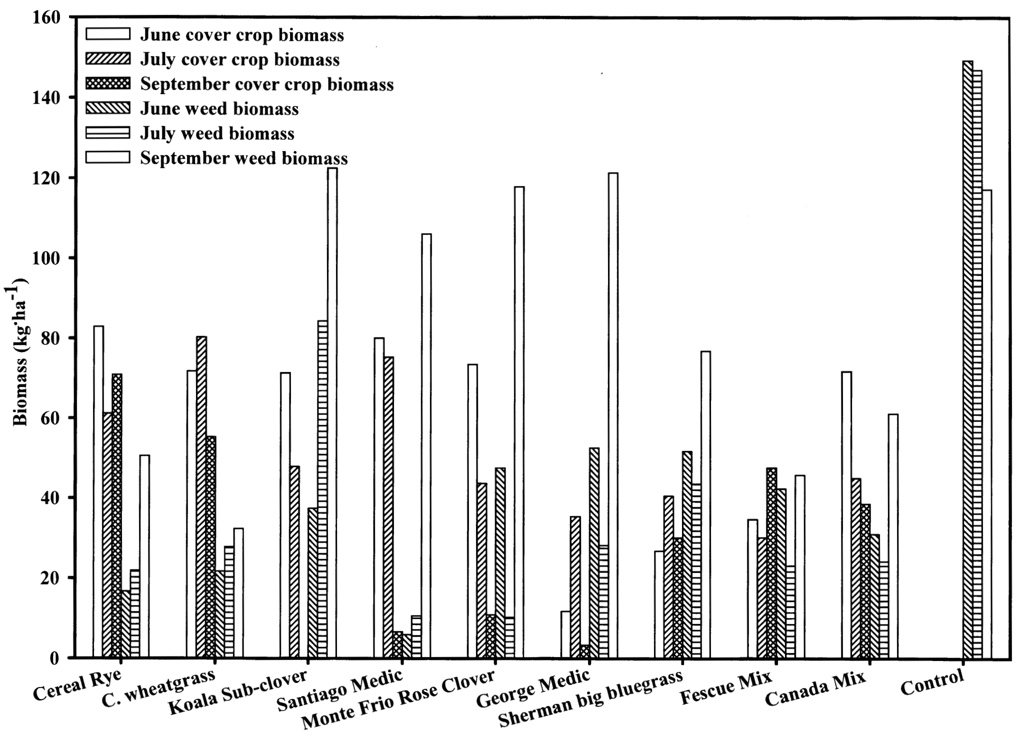

Figure 3 Biomass of cover crops and weeds in commercial vineyard plots, 1999. Canada mix consists of Fairway crested wheatgrass, pubescent wheatgrass, and perennial ryegrass. Fescue mix consists of tall, hard, and sheep fescues. Control plots consist of resident vegetation.

and high biomass production that can shade light-sensitive weed species and provide interspecific competition.

Average biomass (kg·ha^{-1}) was highest for cereal rye, followed by Santiago burr medic, Monte Frio rose clover, crested wheatgrass, and the Canada mix in June (Figure 3). In July, many of the same species produced high biomass: specifically, crested wheatgrass, Santiago medic, cereal rye, and the Canada mix. In September, cereal rye again had the highest biomass, but much of that was stubble and straw because of mowing. Overall, the average biomass over three months (June, July, and September) was highest in cereal rye, crested wheatgrass, Santiago medic, and the Canada mix. However, higher biomass in cereal rye plots did not necessarily translate into the least weed biomass late in the season; alternatively, crested wheatgrass had the least weed biomass of the best performing cover crop entries in September. Weed biomass was greatest in cover crop plots with the least vegetative cover (Koala sub-clover), especially in September (Figure 3).

The Canada mix grew well early in the season and then declined, a pattern which appeared to be created by offset emergence of perennial ryegrass, crested wheatgrass, and pubescent wheatgrass. Perennial ryegrass germinates in March, followed by the two wheatgrass cultivars in May. In some cover crop blocks (for example, Monte Frio rose clover), maximum biomass declined throughout the season as many of the cover crops died, most likely due to low rainfall (<1 mm, 1 June through 31 August) and warm temperatures (29°C daytime avg., 1 June through 1 August 1999; Figure 2).

Leaf area amounts for cover crop treatments and weeds in the plot changed during June and July. Most plots shifted from being dominated by resident vegetation or weeds to being dominated by cover crop treatments, especially those plots where cover crop entries did not germinate until late June or July (Figure 4). In the Koala sub-clover treatment, the cover crop dominated weeds in the plot, but leaf area of the cover crop declined in July and weeds dominated. In all treatments, leaf area of cover crops decreased between June and July (Figure 4).

The mixes had the added advantage of multiple species with different growth characteristics compared to a single-species planting. The early germination of one grass species provided early weed suppression, while suppression during the latter part of the season was provided by later germinating grass species (Figure 3). Such perennial grasses in the Canada mix can reduce the labor and cost involved in reseeding annual cover crops. Cereal rye with high biomass production and late season straw cover can effectively suppress weeds in either a mix or single species planting. Allelopathic activity has been observed when the cereal rye residue is incorporated into the soil [10]. However, cereal rye is an annual that could increase labor costs for seedbed preparation, planting, and stubble incorporation into the soil.

Soil and vine water status—1999. Xylem water potentials of grapevines were not differentially affected by cover crops (p = 0.72; Figure 5). However, the interpretation of water potential measurements is difficult because of variation in solar radiation and irrigation between measurement dates (Figure 5). Vines near the Fairway crested wheatgrass plots tended to have

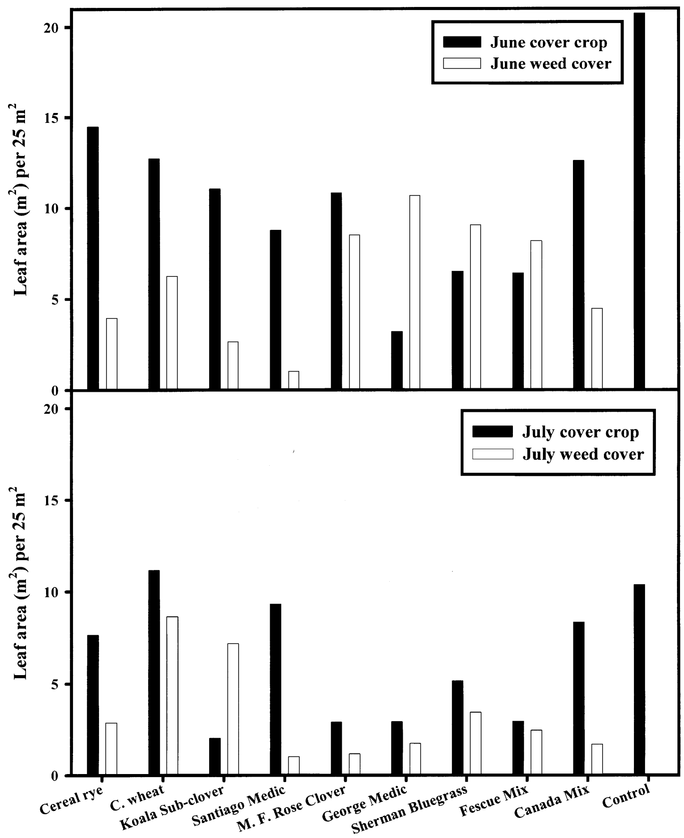

Figure 4 Leaf area of cover crops and weeds in commercial vineyard plots located in Alderdale, WA, 1999. Canada mix consists of Fairway crested wheatgrass, pubescent wheatgrass, and perennial ryegrass. Fescue mix consists of tall, hard, and sheep fescues. Control plots consist of resident vegetation.

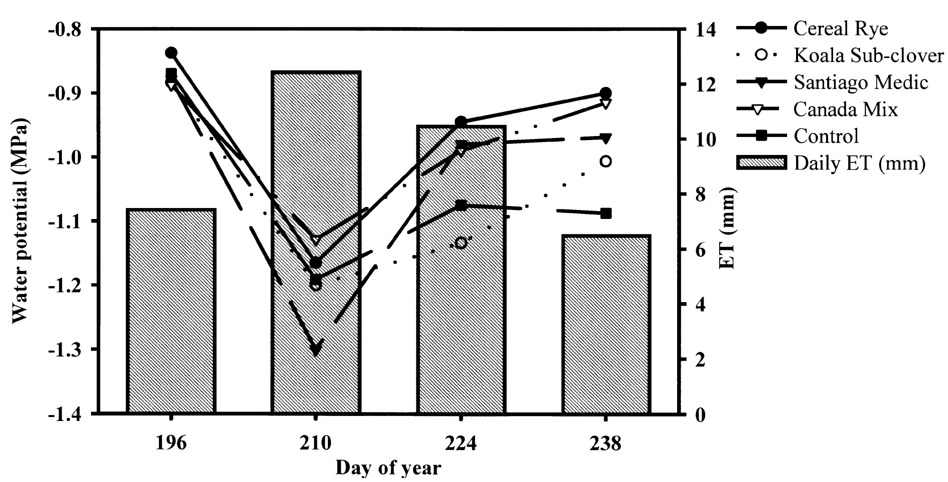

Figure 5 Grapevine water potential in cover crop plots at Alderdale, WA. Measurements were collected on current year's growth near noon, LST. Grass evapotranspiration (ET) are from the Public Agricultural Weather System weather station in Alderdale, WA. Measurements were not significantly different. Control plots consisted of resident vegetation. Canada mix consists of Fairway crested wheatgrass, pubescent wheatgrass, and perennial ryegrass.

the lowest vine water potential, although it was not significantly lower than in other cover crop plots. Wheel traffic appeared to suppress growth along the edges of all cover crops except crested wheatgrass and the Canada mix.

Irrigation regimes began on the same date in all vineyard plots (18 May 1999). No large temporal changes in soil water content were observed at 0.3 or 0.6 m in depth on any given sampling date in interrow spaces (Figure 6). However, soil beneath cereal rye had the least water at 0.3 m and at 0.6 m, suggesting that the season-long presence of this crop actively depletes soil water. Soil below the Canada mix had the most water at both depths. Rainfall during the season was low (<0.1 mm per event; <10 mm during growing season), so that percolation below a few centimeters was unlikely. Field capacities for these sandy or silty loams range from about 27 $cm{\cdot}m^{-1}$ to 28.3 $cm{\cdot}m^{-1}$.

Conclusions

Fairway crested wheatgrass, Canada mix, cereal rye, and Santiago burr medic were identified in this study as viable cover crops for use in drip-irrigated vineyards in the dry conditions of the inland Pacific Northwest. Drought-tolerant grasses like those in the Canada mix show promise in reducing weed growth without the use of herbicides. Their summer dormant characteristics also reduce mowing requirements throughout the season.

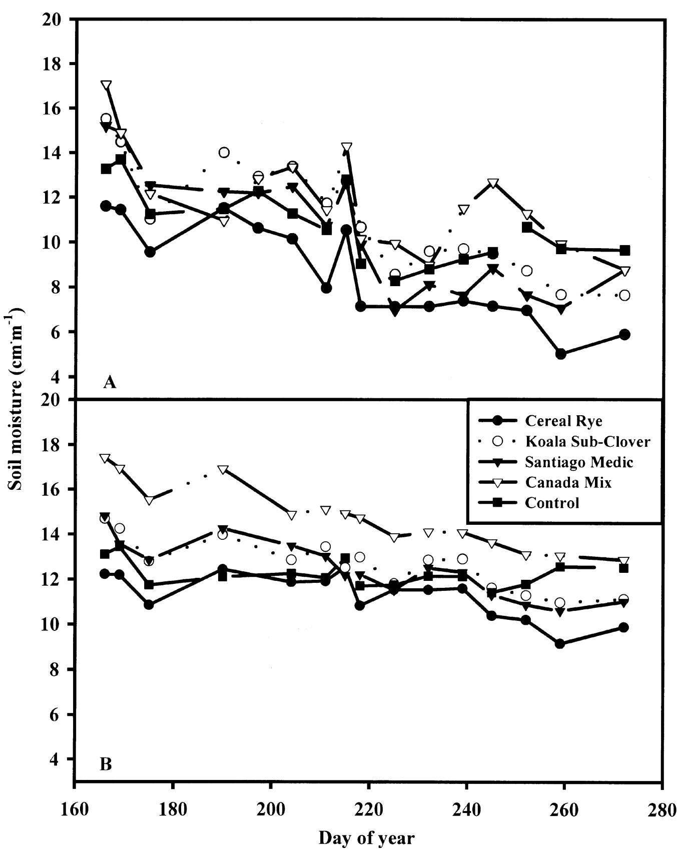

Figure 6 Soil water content in cover crop plots, between grapevine rows at depths of 0.3 (**A**) and 0.6 m (**B**), at Alderdale, WA, 1999. Canada mix consisted of Fairway crested wheatgrass, pubescent wheatgrass, and perennial ryegrass.

Although the legume species established slowly and sparsely in the dry, drip-irrigated vineyard, they may offer an alternative for vineyards using micro- or overhead sprinklers, where water distribution is uniform across the soil. We recommend that further study be completed before eliminating legumes as potential cover crop species in inland Northwest vineyard systems. The prostrate growth habit of many legumes may increase their persistence, once established, and may reduce maintenance costs. In this study, legumes were less effective than grasses. Legumes may have been more effective if planted at 2 cm or with earlier sowing in the fall. Broadcast seeding, including seedbed preparation with a ringroller, irrigation for establishment, and growing a mixture of cover crops may help legume establishment.

Additionally, the foreign medics that performed well in the 1998 screening trial (*M. rigidula*, *M. orbicularis*, *M. scutellata*, and *M. littoralis*) have definite potential for development of vineyard cover crops. These were uncultivated species and therefore are not available for commercial plantings at the present; however, research should be conducted to develop cultivars of these medics for future use to increase biodiversity in the vineyard.

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