Winter Annual Legumes for Use as Cover Crops in Row Crops in Northern Regions: I. Field Experiments

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ABSTRACT

Weed suppression is one of several benefits achieved by including a cover crop in a cropping system. A requirement for developing cover crop systems is to find species and cultivars which are adapted for the local climate and latitude, prevent weed infestation, and do not compete with the main crop. Two experimental series were established at three locations in Norway to evaluate the ability of different species for use as cover crops in vegetable production. The first series of experiments was with subclover (*Trifolium subterraneum* L.) cultivars sown at different dates throughout the summer and the second with different winter annual legume species sown in late summer. Winter hardiness, life cycle, growth characteristics, and weed suppression ability of winter annual legumes sown in the autumn were studied. The experiments showed the following ranking of winter hardiness: hairy vetch (*Vicia villosa* Roth.) (best), black medic (*Medicago lupulina* L.), crimson clover (*Trifolium incarnatum* L.), and subclover (poorest). Time of flowering and senescence, factors related to competition in cover crop systems, showed that subclover was the most promising species followed by crimson clover and hairy vetch–black medic. The winter annual legume species showed the ability for natural reestablishment in the second autumn. Hairy vetch showed the highest biomass production, the lowest regrowth ability after mowing, and the best weed suppression. Subclover showed a very promising life cycle for the use as living mulch; however, more winter hardy cultivars or species with similar growth characteristic are needed before common commercial use in northern regions. In conclusion, until more suitable species or cultivars are found or developed through plant breeding, hairy vetch is the most promising winter annual cover crop under Norwegian conditions.

Weed suppression is one of several benefits achieved by including a cover crop in a cropping system. Many studies have indicated less weed suppression in cropping systems with plant residues than in systems with living mulch (Ilnicki and Enache, 1992; Teasdale and Daughtry, 1993; Brandsæter, 1996). However, a serious problem in living mulch cropping systems is yield depression because of competition. Different ways have been suggested to overcome this problem in such cropping systems.

The classical attempts to reduce competition in cover crop systems have focused on chemical or mechanical suppression of mulch growth or screening for less competitive cover crops. Reducing interference between a white clover (*Trifolium repens* L.) living mulch and sweet corn (*Zea mays* L. var. *saccharata*) by chemical suppression or mechanical suppression has been reported by Vrabel (1983) and by Grubinger and Minotti (1990), respectively. Reduced interference by mechanical suppression of white clover and subclover living mulch in white cabbage (*Brassica oleracea* var. *capitata* L.) is reported by Brandsæter et al. (1998). Nicholson and Wien (1983) screened turfgrasses and clovers to find less competitive mulches for sweet corn and cabbage.

A third way to avoid or decrease the competition in such systems is to intercrop a main crop and a cover crop with a synchronized onset of maximum vegetative growth. This synchronization of cover crop and main crop could be achieved in different ways. Müller-Schärer and Potter (1991) concluded that cover plants should be seeded to emerge in the middle of the vegetation period of the main crop, e.g., in field-planted leek (*Allium porrum* L.). De Haan et al. (1994) have studied the opposite way to avoid interference problems in cover crop systems in the north central region of the USA. They tried to develop a spring seeded smother plant that had been selected for its ability to suppress weeds without affecting crop yield. This cover crop flowered 3 wk after emergence and began senescence 5 wk after emergence (D.L.Wyse, personal communication). Another approach suggested by Ilnicki and Enache (1992) was to use winter annual legumes, e.g., subclover as living mulch. Winter annual legumes sown in late summer grow vegetatively during autumn, become "dormant" in winter, and resume vegetative growth the following spring. Later in the spring or early summer the plant flowers, senesces, and dies. Because of this unique life cycle, a main crop transplanted into the senescencing mulch would be able to use all available water and nutrients. Experiments done by Ilnicki and Enache (1992) in New Jersey, USA, with subclover living mulch showed excellent weed control and no yield depression in corn, sweet corn, cabbage, snap beans (*Phaseolus vulgaris* L.), and tomato (*Lycopersicum esculentum* Mill.). Subclover has the ability to reestablish naturally from seed produced in the spring. Ilnicki and Enache (1992) introduced the idea of growing subclover as a continuous cover crop without the need for seeding every year. A second approach to use a winter annual legume as a cover crop was suggested by Abdul-Baki and Teasdale (1993). This approach calls for sowing the cover crop, e.g., hairy vetch, in the autumn and mowing it immediately before transplanting the main crop in the spring.

The experiments of Ilnicki and Enache (1992) and Abdul-Baki and Teasdale (1993) have shown that winter annual legumes are very suitable as cover crops. A requirement for developing cover crop systems with winter annual legumes is to find species and cultivars which are adapted for the local climate and latitude. To avoid competition with the main crop in the subclover cropping system suggested by Ilnicki and Enache (1992), it is essential to use species and cultivars which have a low canopy height and terminate vegetative growth early in the summer. Additionally, the ability to reestablish naturally in the autumn from seeds produced in the spring and early summer would be a useful property.

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In the hairy vetch cropping system suggested by Abdul-Baki and Teasdale, to avoid yield depression it is of vital importance that cover crop regrowth after mowing is limited. In this cropping system, considerable biomass is needed to suppress weeds after mowing. Rapid ground cover growth in the autumn and at the start of vegetative growth in the spring is important to prevent weed infestation in these winter annual legume cropping systems. Therefore, this study was initiated to investigate the following aspects of winter annual legumes: winter hardiness, biomass accumulation and time of termination of vegetative growth, canopy height, regrowth ability after mowing, time of flowering and senescence, ability for rapid ground coverage, and weed suppression.

MATERIALS AND METHODS

The first field experimental series (1993-1994) was located at the research station of the Plant Protection Centre, Ås (59°40′N, 10°46′E), at Jæren (58°47′N, 5°41′E), and at Løken Research Station (61°7′N, 9°4′E). The trial locations were similar in a 2-yr running second experimental series (1994-1995 and 1995-1996), except that the latter location was replaced by Apelsvoll Research Centre, Division Landvik, Grimstad (58°20′N, 8°31′E) and Jæren was omitted in the second year. Løken was chosen for its continental climate which was in contrast to those of Jæren and Landvik which have typical coastal climates. Ås is characterized with a continental climate moderated by its proximity to the Oslofjord. Figure 1 shows monthly average and normal temperatures (averages of 1961–1990) of daily mean temperatures for the experimental locations for each year.

Experiment 1: Subclover Cultivars

General. The trial design was a randomized complete block, split plot with three replications, with a 5 by 10 factorial at Ås and a 3 by 10 factorial at Jæren and Løken. Five sowing dates at Ås, and three sowing dates at Jæren and Løken, composed the main treatments. Nine subclover cultivars (Daliak, Esperance, Geraldton, Green Range, Karridale, Mount Barker, Nuba, Seaton Park, and Woogenellup) and one red clover (*Trifolium pratense* L.) cultivar (Molstad) were the subplot treatments. The main plot and subplot dimensions were 6.00 by 6.65 m and 1.33 by 3.00 m, respectively.

The cover crops were sown on the following dates: (i) 12 May, (ii) 14 June, (iii) 15 July, (iv) 5 August, and (v) 26 August. The trials located at Jæren and Løken were sown only on the three latter dates.

Seeding rates for the subclover and the red clover were 27 and 20 kg ha^{-1}, respectively. The seeds were mixed with quartz sand to obtain a uniform distribution. The mixture was broadcasted by hand. The seeds were worked into the soil and irrigated, if necessary, to obtain uniform establishment. Plots were hand weeded for weed control. Soil classification and pH were as follow: Ås, loam-sandy loam (160 g kg^{-1} clay, 320 g kg^{-1} silt, and 520 g kg^{-1} sand) and pH 6.3; Jæren, peat (209 g kg^{-1} organic matter) and pH 5.4; and Løken, loam (80 g kg^{-1} clay, 430 g kg^{-1} silt, and 490 g kg^{-1} sand) and pH 5.1. Fertilizer rate ha^{-1} was 25 kg N, 7 kg P, and 20 kg K. Fertilizer was broadcasted one day prior to sowing.

Vegetative Growth during Autumn and Spring. Biomass of all cover crops was assessed on the following dates in the autumn 1993 and spring 1994, respectively: Løken on 23 to 24 September and 5 May, Ås on 1 to 5 October, and 15 April, and Jæren on 7 October and 1 April. The biomass measurements were carried out by cutting and collecting all

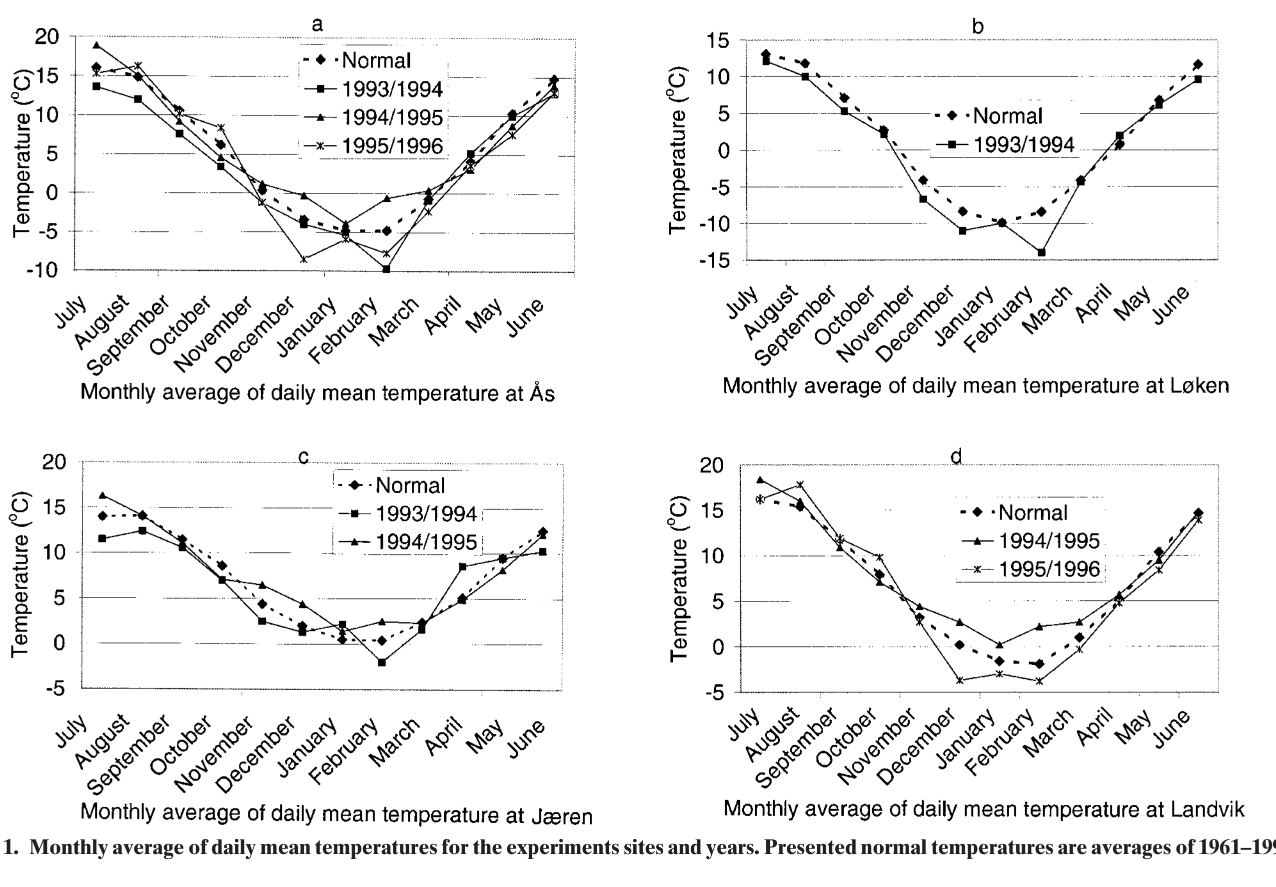

Fig. 1. Monthly average of daily mean temperatures for the experiments sites and years. Presented normal temperatures are averages of 1961–1990.

Table 1. Biomass dry weight in autumn (mid-October 1994) and spring (early May 1995) of winter annual legumes, white clover and red clover sown in the autumn of 1994.

Species/cultivar	Ås Autumn	Ås Spring†	Landvik Autumn	Landvik Spring†	Jæren Autumn	Jæren Spring†
	g m^{-2}					
1. Subclover Mount Barker	12.5b	0	5.7b	9.7c	7.7bc	13.6b
2. Subclover Nuba	11.5b	0	7.2b	53.6bc	6.7bc	42.6b
3. Hairy vetch Welta	22.7a	125.1a	28.7a	311.8a	13.7a	109.5a
4. Hairty vetch AU Early Cover	23.8a	0	20.1a	0	13.0a	0
5. Crimson clover	11.2b	0.1	6.9b	102.9b	7.2bc	17.3b
6. Black medic	2.9c	3.8b	0.6c	0.1	1.3c	0.1
7. White clover‡	4.7c	4.2b	–	–	–	–
8. Red clover‡	3.9c	10.3b	–	–	–	–
$P_{species/cultivars}$:	0.015	0.01	0.001	0.003	0.024	0.002

† Means in the same column followed by different letters are significantly different at $P = 0.05$. The statistical analyses were carried out on logarithmic transformed values and results presented are arithmetic means. Species/cultivars not followed by a letter were not included in the statistical analyses.
‡ Not included in the experiment at Lanvik and Jæren.

the aerial biomass within two quadrats of 0.25-m^2 randomly placed in each subplot. The cutting procedure was done with a scissors and cutting to a stubble height of 2 to 3 cm. The biomass was oven-dried for 72 h at 60°C and then weighed.

Soil Coverage and Canopy Height. The space occupied by living and dead cover crop mulch, as indicated by percentage ground coverage, was visually estimated on the total sub plot area (1.30 by 3.00 m). The area covered by living and dead mulches and area not covered by mulch, added up to 100%. The same person at all sites and dates estimated the ground coverage. Visual estimation of crop and weed coverage is frequently used in scientific experiments (Miller and Callihan, 1995; Weber et al., 1995; Brandsæter et al., 1998). At Ås, the assessments were done every second week during the summer and autumn in 1993, at Jæren and Løken only on the dates of biomass measurements. On the same dates, canopy height was measured at 5 different positions in each plot and the means were used in the statistical analyses.

Flowering. For all sowing dates at Ås, date of flowering onset was assessed on 10 randomly harvested plants from each plot. On the same plants, the number of flowering plants were counted 60, 75, and 90 d after sowing.

Experiment 2: Winter Annual Legumes

General. The trial design was a randomized complete block design with three replications. The plot dimensions were 1.50 by 5.00 m and 3.50 by 4.00 m for the first and second year, respectively. The cover crops were sown on 15 to 19 Aug. 1994 and 8 to 10 Aug. 1995. The legumes were sown in areas previously used for cereal and vegetable production, except for the Jæren location in which the preceding crop was grass. However, early in the season in the year of sowing the legumes, the area was mechanically fallowed.

The experiments included subclover, hairy vetch, crimson clover, black medic, white clover, and red clover. Red clover and white clover, two commonly used legumes in Norway, were included as control species for evaluation of winter hardiness. Cultivar names and the location of the species are given in Table 1 and Table 2. All of the assessments mentioned, including vegetative growth during autumn, spring and early summer, cover crop coverage, canopy height, time of flowering, and weed growth in the plots were carried out the first year (1994-1995). For the second year (1995-1996), only biomass and cover crop ground coverage in autumn and spring were assessed.

Seeding rates in kilograms per hectare for the cover crops were as follow: subclover and crimson clover, 27; black medic and red clover, 20; hairy vetch, 70; and white clover, 10. Seeds from all species were inoculated with a proper *Rhizobium* bacteria just before sowing. A self propelled ØYJORD PLOT SEEDER (Jens A. Schou mek. verksted, Drøbak, Norway), with row width 13.5 cm and seeding width 1.5 m, was used for sowing the cover crops.

The soil textures and pH were as follow: Ås, loam-sandy loam (160 g kg^{-1} clay, 320 g kg^{-1} silt, and 520 g kg^{-1} sand) and pH 6.1; Jæren, texture not determined (73 g kg^{-1} organic matter) and pH 5.7; Grimstad, loamy sand (100 g kg^{-1} clay, 150 g kg^{-1} silt, and 750 g kg^{-1} sand) and pH 6.0. Only the Ås location was fertilized. The fertilizer rate was 25 kg N, 7 kg P and 20 kg K ha^{-1}.

Vegetative Growth during Autumn, Spring, and Early Summer. For the 1994-1995 experiment, cover crop biomass was measured once in autumn and four times during spring and early summer at 3-wk intervals. The spring and early summer regrowth assessments were measured 3 wk later. Dates of the assessments are shown in Fig. 2. Biomass measurements for the 1995-1996 experiment were carried out in autumn, 21

Table 2. Biomass dry weight and soil coverage (percent of soil surface) in autumn (late September 1995) and spring (late May 1996) of winter annual legumes, white clover and red clover sown in the autumn of 1995.

Species/cultivar	Ås Autumn†	Ås Spring†	Ås Autumn†	Ås Spring†	Landvik Autumn†	Landvik Spring†	Landvik Autumn†	Landvik Spring†
	— Dry weight (g m^{-2}) —		Soil coverage (percent)		— Dry weight (g m^{-2}) —		Soil coverage (percent)	
1. Subclover Nuba	–‡	–	–	–	38.5c	0	72b	0
2. Hairy vetch Welta	93.6a	115.7b	97.5a	95a	170.0a	14.8b	100a	13b
3. Crimson clover	–	–	–	–	61.8b	0	78b	0
4. Black medic Virgo Pajberg	49.8b	2.8c	87b	6c	48.2bc	4.5c	80b	9b
5. White clover Milkanova	33.8b	24.4c	77c	45b	12.8d	25.0a	38c	23a
6. Red clover Molstad	49.3b	147.5a	83bc	95a	–	–	–	–
$P_{species/cultivars}$	0.0018	0.0001	0.018	0.001	0.001	0.001	0.001	0.037

† Means in the same column followed by different letters are significantly different at $P = 0.05$. Species/cultivars not followed by a letter were not included in the statistical analyses.
‡–, Not included at this location.

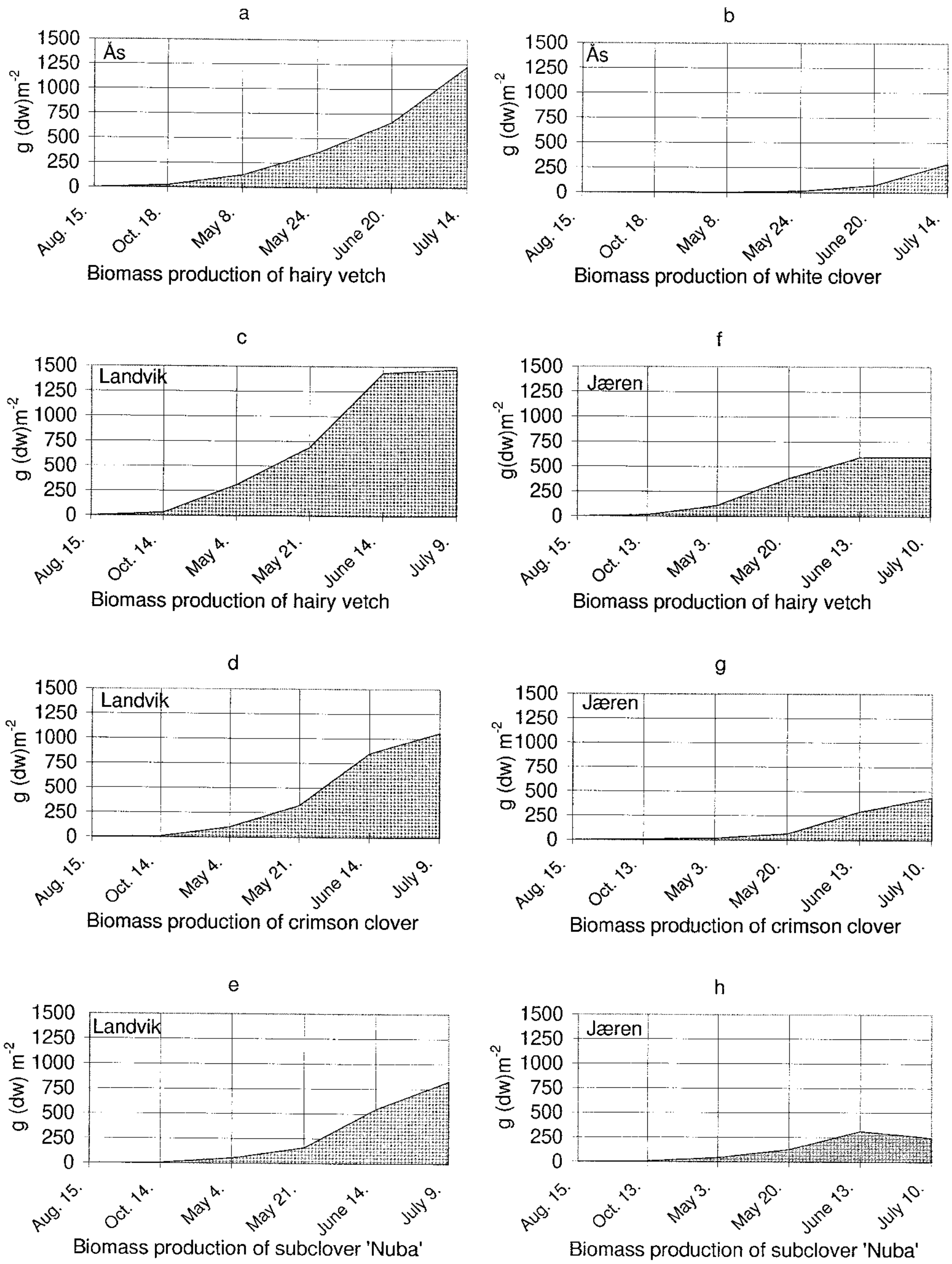

Fig. 2. The development of dry weight of biomass (sum of living and dead plant material) of different winter annual legumes and a white clover cultivar, from sowing in the autumn 1994 until summer 1995 at three locations in Norway.

to 27 September, and spring, 26 to 28 May. The biomass measurements were carried out by cutting and collecting all the aerial biomass above a stubble height of 2 to 3 cm within four rectangles of 0.125 m^2 randomly placed in each subplot with a scissors. The biomass was oven-dried for 72 h at 60°C and then weighed.

Cover Crop Coverage, Canopy Height, and Time of Flowering. Coverage of living and dead plant material was visually estimated at 3-wk intervals in spring and early summer. On the same dates, canopy height and time of flowering were recorded. These measurements were carried out similar to the subclover experiment.

To measure the potential for reestablishment from seeds of the winter annual legumes, the ground coverage was, for both living and dead plant material, visually estimated in early August, early September, and early October at the Ås and Grimstad locations.

Weeds. In the autumn of 1994, weed emergence was recorded on the same dates and in the same rectangles as for the cover crop biomass assessment. Additionally, weed emergence and total weed dry weight were recorded four times during spring and early summer. These measurements were carried out on the same dates and in the same rectangles as for the cover crop biomass assessments. The weed biomass was oven-dried for 72 h at 60°C and then weighed.

Statistical Considerations

Analysis of variance was carried out in both experiments. The assumptions for normality and variances underlying the statistical analyses were tested for all response variables. To stabilize variance, some response variables were transformed (see Results). If the statistical analyses were carried out with transformed values, it is mentioned in the tables or figures. A testing procedure (SAS Institute Inc., 1992) for detecting outliers was performed. Newman-Keuls multiple tests (SNK multiple-stage test) were used for comparing treatments (SAS Institute Inc., 1988).

RESULTS AND DISCUSSION

As described in the introduction, these experiments were carried out to evaluate the cover crops in two different cover crop systems, both established in late summer or autumn; to wit, (i) the use of low growing legumes, e.g., subclover (Ilnicki and Enache, 1992), as living mulch, and (ii) mowing the cover crop, e.g., hairy vetch (Abdul-Baki and Teasdale, 1993), immediately before transplanting the main crop. For both approaches, it is important to obtain a rapid ground coverage and biomass accumulation in autumn to prevent weed infestation. The next factor, which is extremely important in northern regions, is winter hardiness. For species with a winter or summer annual life cycle, flowering characteristic as influenced by the interaction between species–cultivars and time of sowing is an indication of winter survival potential. Furthermore, time of flowering, senescence, canopy height, and regrowth ability after mowing in the spring or early summer, should give information about competition in the cover crop systems. Rapid biomass accumulation and ground coverage development during spring and early summer are very important in both systems for obtaining good effects on weeds and pests and for the potential of green manure effects (Brandsæter et al., 1998). Finally, the ability to reestablish naturally in the autumn from seed produced in the early summer would be a valuable property in the living mulch system.

Establishment in the Autumn

In the subclover experiment, no significant differences in ground coverage appeared at any sowing date between the cultivars (data not presented). All cultivars sown on the first three dates completely covered the ground by late autumn. When sown on 5 August, the coverage of the cultivars varied between 70 and 80%. The coverage on plots sown on 26 August was about 10% for all the cultivars. The cultivar biomass production in autumn for each location are presented in Table 3.

Hairy vetch was the most promising species both for ground coverage and biomass accumulation (Tables 1 and 2, and Fig. 2 and 3) in the second experiment. Subclover and crimson clover and black medic in 1995-1996 also showed better ability for ground coverage and biomass accumulation than white clover. However, not all comparisons were significantly different (see Tables 1 and 2).

Life Cycle, Winter Survival, and Vigor in Spring

As already pointed out, time of flowering in the year of sowing is important for potential winter survival. In the subclover experiment the following range of earliness of flowering was found: (i) Daliak and Geraldton (earliest); (ii) Woogenellup; (iii) Seaton Park, Esperance, and Green Range; and (iv) Nuba, Karridale, and Mount Barker (latest). All cultivars flowered when sown on 12 May. When sown on 14 June, the cultivars in the fourth group were the only ones that did not show 100% flowering in late autumn (data not shown). This difference of sowing on 14 June was statistically significant both within and between these three late cultivars and all the other earlier cultivars in first three groups. The subclover experiment showed that all cultivars flowered and appear as summer annuals when sown in mid-June or earlier. Frost hardiness of subclover is lost after flowering, as was confirmed in a growth chamber experiment (Brandsæter et al., 2000). When sown at Ås and Løken on 15 July or later, none of the cultivars flowered in late autumn and they appeared as winter annuals. Even then they were not winter hardy enough to stand the winter at these locations, and all cultivars, independent of sowing time, were dead in the spring (Table 3). At Jæren, some flowering plants of Geraldton and Daliak sown on 15 July appeared in late autumn and none of these two cultivars survived winter as expected. The four cultivars Green Range, Nuba, Woogenellup, and Esperance showed some ability to survive (see Table 3). However, even at Jæren the winter hardiness was not very good that year. The statistical analyses of biomass at springtime showed a significantly higher biomass for the red clover cultivar than all the subclover cultivars. Because of a lack of seed, the cultivar Mount Barker, which has been reported to be one of best cultivars for winter-survival in USA (Enache, 1989) was not sown in late July at Jæren.

Table 3. Biomass dry weight of subclover cultivars and cv. Molstad red clover sown on 15 July in the subclover experiment.†

	Ås		Løken		Jæren	
Cultivar	**Autumn**	**Spring**	**Autumn**	**Spring**	**Autumn**	**spring**
	g m^{-2}					
Daliak	289.6	0.0	184.0	0.0	26.7	0.0 c
Esperance	288.5	0.0	156.8	0.0	34.7	2.4 c
Geraldton	275.9	0.0	163.8	0.0	22.7	0.0 c
Green Range	374.6	0.0	166.0	0.0	21.3	7.5 b
Karridale	324.8	0.0	151.8	0.0	37.3	0.0 c
Mount Barker‡	301.1	0.0	–	–	–	–
Nuba	386.8	0.0	128.2	0.0	26.7	7.9 b
Seaton Park	302.2	0.0	162.9	0.0	25.3	0.0 c
Woogenellup	399.4	0.0	178.1	0.0	32.0	9.1 b
Molstad	258.5	91.5	115.7	59.6	17.3	15.2 a
$P_{species/cultivars}$	–	–	–	–	–	0.001

† Means with different letters are significantly different at $P = 0.05$. Only results from Jæren were included in the statistical analyses.
‡ Not included in the experiment at Løken and Jæren.

Table 1 shows that hairy vetch cultivar AU Early Cover was completely dead in the spring of 1994 at all locations. Both subclover cultivars were completely dead in the spring at Ås. Only some individual plants of black medic were still alive at Landvik and Jæren. Species–cultivars, location, and the interaction between the two factors appeared significant in the statistical analyses of dry weight in spring. Because of the interaction between species–cultivar and location, separate statistical analyses were carried out for each location. At all three locations, hairy vetch Welta in spring showed

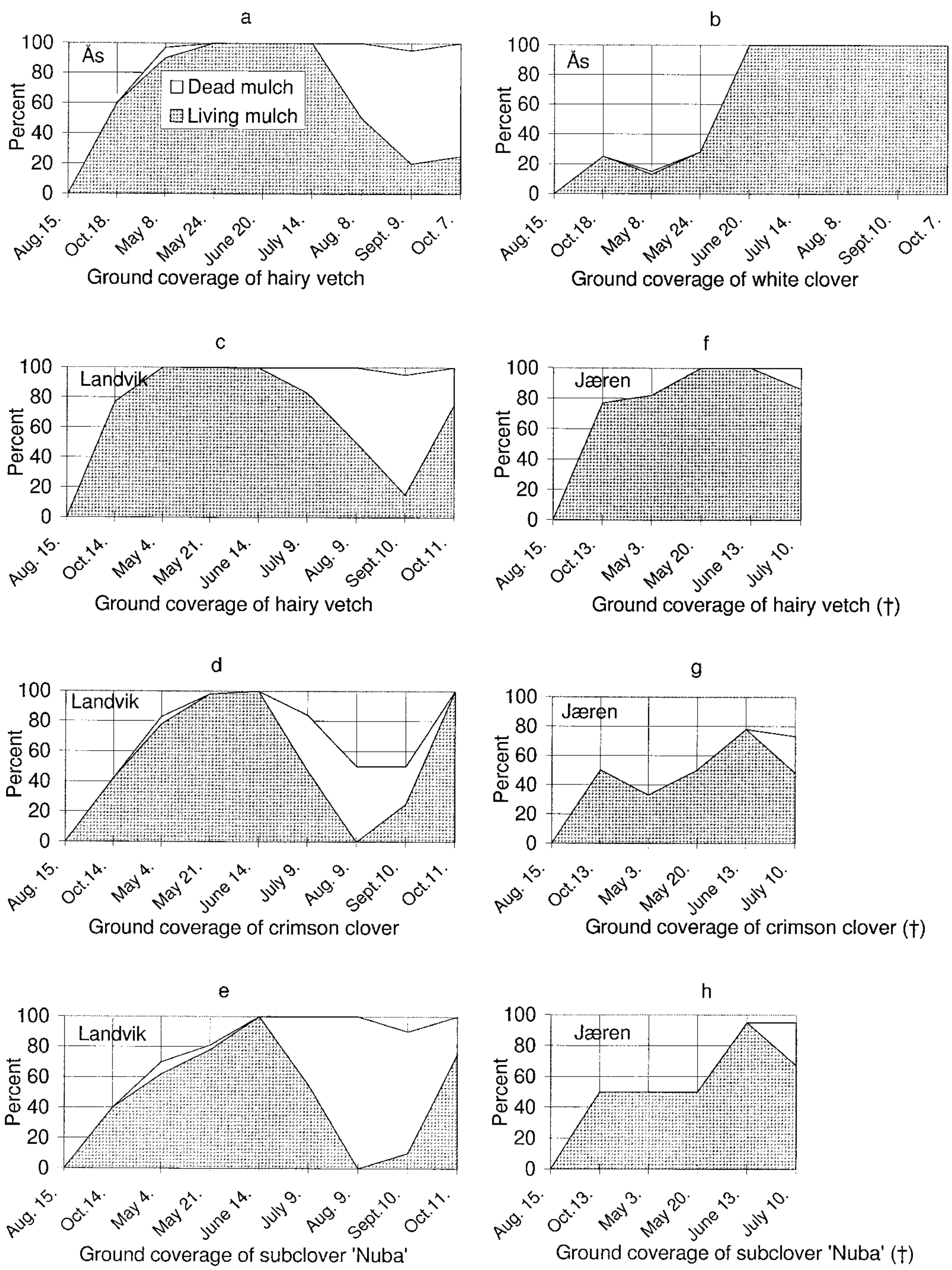

Fig. 3. The development of ground coverage (living and dead mulch) of different winter annual legumes and a white clover cultivar at three locations in Norway, from sowing in the autumn of 1994 until autumn of 1995. †Not assessed in the autumn of 1995.

a significantly higher biomass dry weight than all the other species–cultivars. At Ås, no significant differences appeared between black medic, white clover, and red clover. At Landvik, crimson clover showed a significantly higher biomass dry weight than subclover Mount Barker. Biomass production of subclover Nuba was higher than for Mount Barker. However, the difference was not significant. At Jæren no significant differences between crimson clover and subclover cultivars appeared. Subclover Nuba exhibited a higher biomass dry weight than crimson clover, contrary to the results at Landvik.

Because of the poor performance of subclover at Ås, this species was omitted in the experiment in 1995-1996. Table 2 shows that all species survived at Ås; however, black medic did rather poorly. Redclover showed the highest biomass, followed by hairy vetch, white clover, and black medic. The statistical analyses showed significant differences between all species. Subclover and crimson clover this year were completely dead in the spring at Landvik. Black medic and also, rather surprisingly, hairy vetch showed poor winter survival at Landvik. The difference in hairy vetch in winter survival between Landvik and Ås showed that winter temperature is not the only important factor for winter survival. White clover was the only species that showed satisfactory survival at Landvik this year.

The overall results showed the following ranking of biomass in spring as an expression of winter hardiness among the winter annual species: hairy vetch Welta (best)>black medic>crimson clover>subclover (poorest). Hairy vetch seemed to be the species best suited for cold climates; its fitness in terms of winter survival seems not to differ much from red clover and white clover. Crimson clover and the most winter hardy cultivars of subclover seemed to have some potential for winter survival; however, they are only suitable for the south and southwest coasts of Norway. It is important to take into consideration that the winter of 1993-1994 was rather normal and the winter of 1994-1995 was warm (see Fig. 1), but the exceptionally cold winter of 1995-1996 killed both species.

The conclusion of winter hardiness is to some degree supported by the results of a growth chamber freezing experiment carried out by Brandsæter (1996). In this experiment the relative root lengths after freezing of black medic, hairy vetch, and crimson clover were generally greater than the subclover cultivars. However, the differences were not significant for all comparisons. Surprisingly, the frost hardiness of hairy vetch AU EarlyCover was as good as for Welta in the growth chamber experiment. This cultivar showed promising winter hardiness, better than subclover and crimson clover, in experiments in North America (J.R. Teasdale, personal communication). A response to day length, as a result of degree of latitude, could be an explanation for the loss of winter hardiness under Norwegian field conditions. That means that this early cultivar may reached flower initiation because of early sowing and thereby may lose its frost hardiness.

Biomass and Ground Coverage Development in Early Summer

Only species–cultivars which exhibited satisfactory winter survival in the 1994-1995 experiment will be further presented (see Fig. 2–5) and analyzed. In cover crop systems, including mowing the cover crop, it is important to obtain as thick a layer of plant residues as possible. At Ås, hairy vetch exhibited a significantly higher biomass dry weight than white clover on all sampling dates. The differences between these species were considerable (see Fig. 2a and b). Because of big differences in biomass production at Landvik and Jæren and a significant interaction between these two locations and species, the analyses were carried out separately. At Landvik, the biomass dry weight of hairy vetch was significantly higher than for crimson clover and subclover on the three sampling dates, except for crimson clover on 9 July. Furthermore, the biomass of crimson clover was significantly higher than for subclover on all sampling dates, except 9 July. At Jæren, the biomass of hairy vetch was highest followed by crimson clover and subclover on all sampling dates. However, the difference between hairy vetch and crimson clover was significant only on the first sampling date. Biomass of hairy vetch was significantly higher than for subclover on all sampling dates. The difference between crimson clover and subclover was not significant at any date.

Biomass production and ground cover development of the species were strongly correlated. Because the species–cultivars which survived winter at Landvik and Jæren were similar and quite different from Ås and the statistical analyses of ground coverage of the interaction between species–cultivars and location gave a significant difference, the results from the two former locations were analyzed together in the 1994-1995 experiment. Separate analysis of the results from Ås (Fig. 3) showed that the ground cover in late autumn was significantly better in plots with the hairy vetch Welta than in plots with white clover. Hairy vetch also developed a significantly better ground cover than all the other species–cultivars at Landvik and Jæren (Fig. 3). No significant differences appeared between subclover Nuba and crimson clover. The cover crops covered the ground significantly more rapidly at Landvik than at Jæren. At Ås, the ground cover in early May of hairy vetch was significantly higher than for white clover. At Landvik and Jæren, hairy vetch performed significantly better than the two other species. Figure 3 shows that hairy vetch had covered the ground by late May at all locations. Complete coverage for white clover at Ås was attained about 30 d later. Crimson clover and subclover Nuba at Landvik developed quite similar to or a little later than hairy vetch. At Jæren, these two species showed less ability for rapid ground cover development. This was probably because of competition from *Poa annua* L. (discussed later). Later in the summer, the growth habit of crimson clover at both locations showed a more open canopy than the other cover crops, and the ground cover decreased.

Cover Crop Regrowth

The effect on regrowth of cutting–mowing the cover crops is presented in Fig. 5. From these data, it can be concluded that cutting date was of vital importance in relation to regrowth ability of subclover and crimson clover. Hairy vetch had generally very little or no regrowth, regardless of mowing time. At Landvik, the ability for regrowth decreased for crimson clover with delayed mowing in spring–early summer. Subclover showed a peak of regrowth when mowed on 21 May. At Jæren, subclover and crimson clover showed a similar peak of regrowth ability when mowed in late May. At Landvik, the regrowth of hairy vetch was significantly lower than for crimson clover and subclover at all cutting dates, except for crimson clover on 14 June. No significant difference appeared between crimson clover and subclover, except on 21 May (see Fig. 5d and e). At Jæren, the regrowth of subclover was significantly higher than for the two other species at the two first dates. Regrowth of hairy vetch at Ås was significantly lower than for white clover on the last two dates. White clover clearly showed an increased ability for regrowth in summer compared to spring.

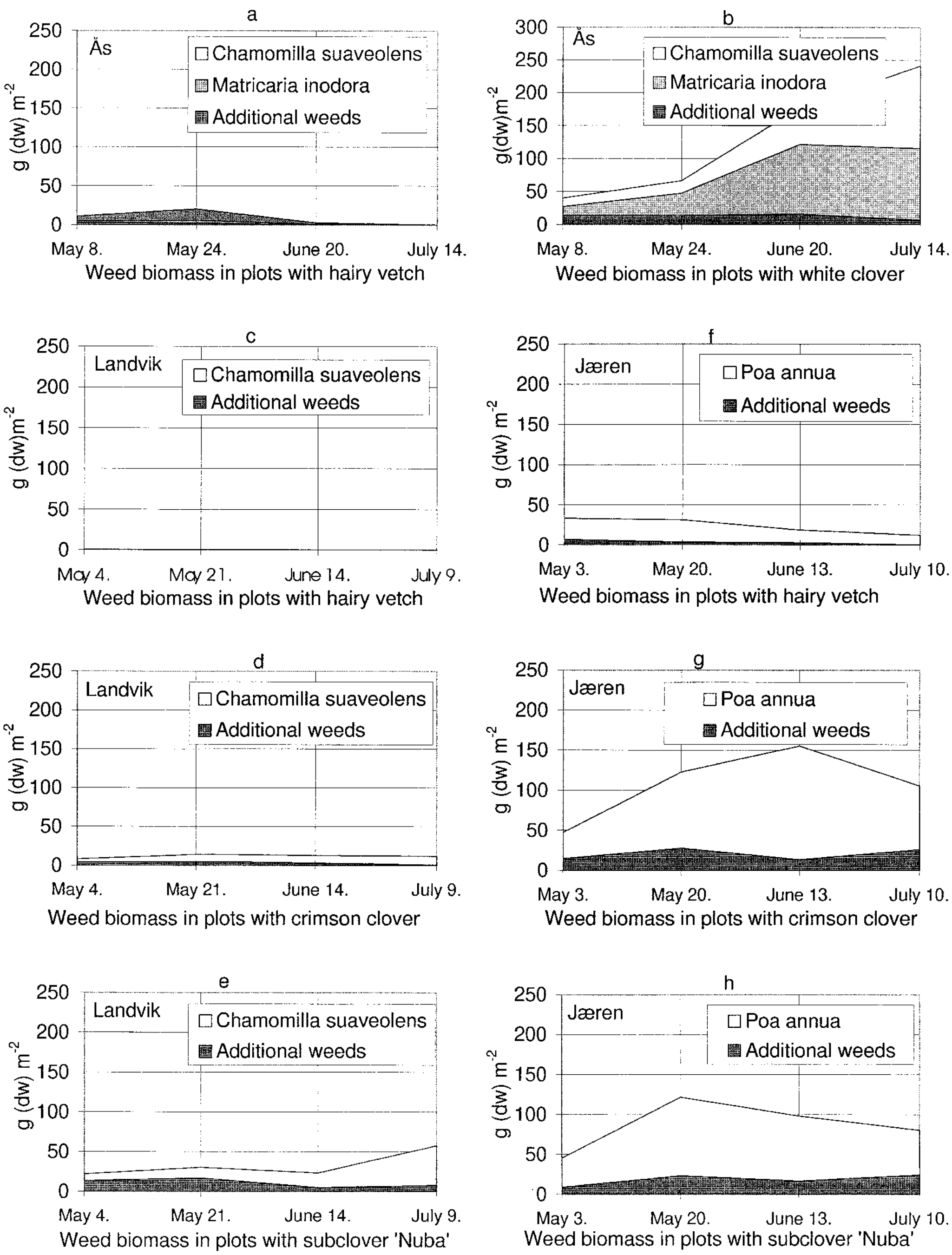

Fig. 4. The development of dry weight of weed biomass in spring and summer after sowing the previous autumn at three locations in Norway. The main weed species are specified. Less frequent weed species are grouped as 'additional weeds'.

All the species in the experiments, except black medic and particularly subclover, have high canopies and must be mowed before transplanting crop plants. To avoid competition, it is important that the species have very little or no ability for regrowth after mowing. Hairy vetch showed very little regrowth ability, especially after mid-May. Hence, this species is a very promising cover crop. Subclover and crimson clover showed more regrowth, but also for these species the ability decreased in mid-June. White clover showed significantly higher regrowth during summer than the winter annual species and would consequently compete heavily with the main crop.

Termination of Vegetative Growth

An early termination of vegetative growth could be important in cover crop systems to avoid competition. In the experiments, three different assessments or estimates were made for the determination of termination of vegetative growth: (i) date of flowering, (ii) biomass accumulation between the last two sampling dates, and (iii) ground coverage of dead cover crop material.

In 1994-1995, subclover (both cultivars) started flowering in mid-May at Landvik and Jæren. Crimson clover and hairy vetch flowered a little later, in the beginning of June and mid-June, respectively, at these locations.

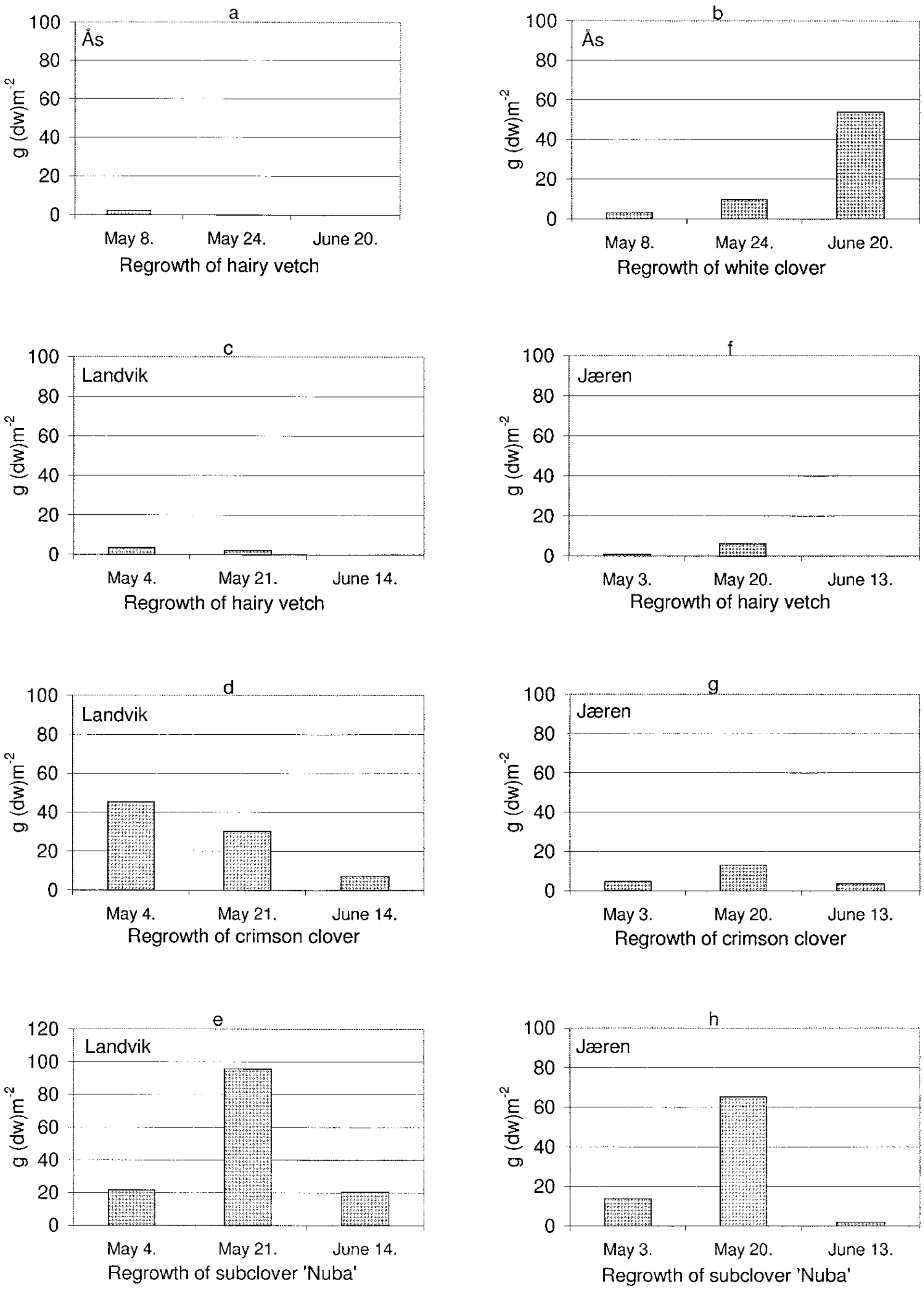

Fig. 5. Dry weight of biomass regrowth (assessed 3 weeks after date of cutting) of different winter annual legumes and a white clover cultivar at different cutting dates at three locations in Norway.

Hairy vetch and black medic flowered in late June at Ås. The latter species flowered throughout the summer (data not shown).

The biomass accumulations (i.e., differences between biomass in mid-June and mid-July) averaged for the Landvik and Jæren locations were crimson clover 176 g m^{-2}, subclover 157 g m^{-2}, and hairy vetch 110 g m^{-2}. However, only differences between locations, which indicated that biomass accumulation was greater at Landvik than at Jæren, appeared significant in the statistical analyses. Significant differences were found between hairy vetch (565 g m^{-2}) and white clover (213 g m^{-2}) at Ås.

In Fig. 3, the appearance of dead plant material originating from the winter annual legumes is also shown. Analysis of differences between species and locations was based on the ground cover assessments in mid-July. Hairy vetch, which was the only winter annual legume at Ås, had not begun senescence at this time. At Landvik and Jæren differences between species and locations appeared significant. There was no interaction between the two factors. The ground cover of dead plant material averaged over locations varied from 37% (subclover Nuba) to 15% (hairy vetch). Subclover Nuba was not significantly different from crimson clover (31%). Subclover and crimson clover were significantly different from hairy vetch. Subclover and crimson clover were completely dead, and hairy vetch was almost dead in early August at Landvik (see Fig. 3). Because black medic did not show senescence during summer at all (data not presented), it is reasonable to expect competition problems.

Canopy Height

In the subclover experiment, the early flowering cultivars, Daliak and Geraldton, generally exhibited the lowest biomass production and the lowest canopy height (data not presented). The maximum canopy heights, averaged over location in the 1994-1995 experiment, during summer were hairy vetch, 53 cm; crimson clover, 55 cm; subclover, 18 cm; and white clover, 37 cm.

Reestablishment

The winter annual species showed a very interesting ability for natural reestablishment from seeds in the second autumn. Exploiting this ability is probably most interesting in the use of subclover. Figure 3 shows that all these species, especially crimson clover and subclover, were reestablished in the autumn of 1995 at Landvik. Hairy vetch also showed some ability for reestablishment at Ås.

Weed Suppression

In the 1994-1995 experiment, the cover crop weed suppression ability was analyzed by measuring weed biomass dry weight in mid-July. The biomass of the dominant and minor weed species in hairy vetch, crimson clover, and subclover Nuba at Landvik and Jæren, and in hairy vetch and white clover at Ås, is presented in Fig. 4. *Chamomilla suaveolens* (Pursh) Rydb. and *Matricaria perforata* Merat, were the dominant weed species at Ås. For Landvik and Jæren, respectively, *C. suaveolens* and *P. annua* were the dominant species.

At Landvik and Jæren, differences between species, location, and the interaction between the factors appeared significant in the statistical analyses of total weed biomass (dry weight). At Landvik, the total weed biomass was significantly higher in plots with subclover than in plots with crimson clover.

At Jæren, there was significantly less total weed biomass in plots with hairy vetch than in plots with subclover or crimson clover. No significant difference in total weed biomass was found between subclover and crimson clover.

Figure 4 shows that *C. suaveolens* and *M. perforate* were abundant in plots with white clover at Ås. Only negligible amounts of weeds were growing in plots with hairy vetch. Total weed biomass was significantly higher in plots with white clover than in plots with hairy vetch at Ås.

The ranking of the species–cultivars in ability to cover the ground in the 1994-1995 experiment was as follows: hairy vetch (most rapid), subclover and crimson clover, and white clover (slowest). Weeds emerging in plots with hairy vetch showed very limited survival. Even winter annual weed species, germinating at the same time as the cover crops, developed very poorly in hairy vetch plots. Also at Jæren, the weed suppression by hairy vetch was better than with subclover and crimson clover, but even hairy vetch did not suppress a dense stand of *P. annua* effectively. Because undisturbed plants of hairy vetch and crimson clover have high canopies, they must be mowed. If an early mowing is required, the weed suppression ability of these species could be reduced. At all locations, there was very little or no germination of weed species in the springtime. However, winter annual weed species growing in plots with subclover and crimson clover, and particularly white clover, must be mowed in springtime.

Suitability as Cover Crops

The main obstacle for the utilization of subclover as a cover crop in Norway is the lack of winter hardiness. Even the most winter hardy cultivars in these experiments can only survive near the south and southwest coasts of Norway. More experiments are needed to clarify the winter hardiness of this species, but utilization in the southern coastal area of Norway should not be completely excluded. To avoid competition in cropping systems necessitating a directly transplanted crop into a living mulch, an early termination of vegetative growth and low canopy height are important. Subclover is the only species among those used in these experiments which has a promising potential in such a cropping system. However, the use of subclover as a living mulch is not without problems. As Ilnicki and Enache (1992) concluded, it may be necessary to mow excessive growth of the subclover to reduce early competition with some crops. However, the second field experiment showed that the regrowth of subclover, after mowing, can be relatively large. Another technique may be to strip till or chemically kill or suppress vegetative growth in the row, prior to, or after, transplanting the crop. Strip tilling in the row would probably cause weed problems in the row. In cabbage, in-row weeds could be controlled by selective flaming (Netland et al., 1994). As the experiments have shown, it may also be necessary to mow weeds growing between rows. The need for mowing to suppress weeds in subclover is also pointed out by other authors (e.g., Lanini et al., 1989). This mowing could be carried out once or twice prior to transplanting the crop. Weed suppressing effects of subclover are probably insufficient if perennials and grass weeds dominate the weed flora.

Hairy vetch is too tall and terminates vegetative growth too late in the summer to be utilized as a living mulch directly. Hairy vetch has to be converted, e.g., by mowing, into an organic mulch, before transplanting the crop. To prevent competition, it is important that the plants do not continue growth after mowing and the present results showed that regrowth of hairy vetch was negligible and less than for the other species. Curran et al. (1994) found in a 2-yr experiment that the control of hairy vetch after mowing was excellent when the vetch flowered early and the weather was warm and dry. However, in the second year, in which the spring was cool and wet, and the hairy vetch was in the late vegetative stage of development, the vetch resumed growth after mowing. After mowing the cover crop, it is important to obtain as thick a layer of plant residues as possible. Almeida (1985) found that cover crops producing more than 450 g (dw) m^{-2} prior to mowing or a chemical treatment were likely to be the most effective for reducing the weed infestation. In the experiment presented here, hairy vetch exceeded this production in early summer and showed the biggest biomass accumulation of the species compared. To obtain satisfactory amounts of plant residues, it could be necessary to delay the date of transplanting or sowing the main crop. Hairy vetch Welta showed the best winter hardiness of the winter annual legume species screened in the experiments. However, even for the cultivars of this species, more experiments are needed to clarify the winter hardiness characteristics.

Because of canopy height and time of the end of vegetative growth, it seems adequate to use crimson clover in the same manner as hairy vetch. However, this species has some drawbacks relative to hairy vetch. First, this species covered the ground later after sowing and the growth habit was more open. Second, the biomass accumulation throughout the whole life cycle seemed to be less than for hairy vetch. Consequently, the weed suppression effect before mowing was not as good as for hairy vetch. Because of lower rates of organic mulch, it seems reasonable to assume that weed suppression after mowing would not be as good as for hairy vetch. Differences between the species in allelopathic potential or speed of degradation of residues may modify this aspect, however. Third, a large degree of regrowth after mowing in the spring and early summer is likely to cause more competition problems. Fourth, winter hardiness is poorer and the use of this species is probably limited to locations with mild winter climates.

Because black medic showed rather poor winter survival this species is not discussed here.

The present results have shown that white clover covered the ground more slowly than the winter annual legumes. Additionally, vegetative growth continued through the whole summer. Numerous studies have shown that yield depression caused by competition is a serious problem in living mulch systems with perennial legumes (Brandsæter et al., 1998; Nicholson and Wien, 1983; Vrabel, 1983). The need has been reported for reducing interference in such cropping systems by chemical suppression (Vrabel, 1983) and by mechanical suppression (Brandsæter et al., 1998; Grubinger and Minotti, 1990).

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