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Interplanting ryegrass in winter leek: effect on weed control, crop yield and allocation of N-fertiliser

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The potential effect of two sowing dates of ryegrass, *Lolium perenne* L. var. Elka as an interplant in winter leek, *Allium porrum* L., on weed control, soil nitrogen allocation and crop yield was studied at two sites in Switzerland. In order to reduce potential competition with the ryegrass, row application of the herbicide methazol (as additional treatment) and increased fertiliser doses in spring (as split-plot treatment) were used, and compared with a weed-free control. Ryegrass was sown 4 weeks (early) and 6 weeks (late) after planting of the leek, allowing for one and two mechanical weed control treatments, respectively, prior to sowing. Under the experimental conditions, intersowing ryegrass 6 weeks after planting resulted in crop yield similar to that in the control plots. Crop quality variates were increased and the overall production system was environmentally more advantageous. The combination of two mechanical weed control treatments followed by ryegrass intersowing suppressed weeds sufficiently without herbicide applications. Approximately 20 kg N/ha could be retained from being washed out over the winter, and *c.* 50 kg N/ha was stored in the interplants up to harvest. The interplants were incorporated into the soil after the harvest to serve as N-source for the subsequent crop. Surplus fertiliser doses in spring increased N-allocation to leek in the control plots. However, when ryegrass was present, it mainly derived a benefit, resulting in only slightly increased N-allocation to leek, or even reduced allocation when overall N-levels in the soil were low. Depending on soil conditions at harvest, full mechanical harvest could possibly be impeded when ryegrass is present. Early ryegrass sowing resulted in severe yield reductions. Row application of the herbicide methazol reduced crop yield in both ryegrass treatments, most possibly due to a direct negative impact of the high herbicide doses on leek growth.

Keywords: leek; ryegrass interplant; weed control; nitrogen allocation

Open field cultivation of vegetables, where several crops are harvested per year, is associated with particularly intensive use of pesticides and fertiliser, as compared with other sectors of plant production (Wallace and Bellinder, 1992; Müller-Schärer and Baumann, 1993; and references therein; Theunissen, 1994). Changes in the attitudes of consumers towards an environmentally more friendly agriculture, the concentration of the agrochemical-industry on a few high-cash crops, and crop-specific and stricter environmental legislation of pesticides have all lead to the situation that familiar pesticides are withdrawn from the horticultural market. This has created the urgent need to re-examine presently used production systems, as alternatives are not yet generally available.

Interplanting[†] has traditionally received much attention by applied entomologists and pathologists aiming at reducing pest numbers and diseases (Ryan, Ryan and McNaeidhe, 1980; Altieri, 1983; Latheef and Ortiz, 1983; Uvah and Coaker, 1984; Altieri, 1988; Coaker, 1988; Müller-Schärer and Potter, 1991; Phatak *et al.*, 1991; Müller-Schärer, Potter and Hurni, 1992a; Theunissen, 1994). In addition, interplanting has also been proposed and used to suppress weeds (Wiles *et al.*, 1989; Müller-Schärer *et al.*, 1991; Phatak *et al.*, 1991; Wallace and Bellinder, 1992) and to prevent erosion and leaching losses of mobile nutrients, such as nitrates, and thus to reduce ground water contamination (Muller, Morlet and Mariotti, 1987; Martinez and Guiraud, 1990; Müller-Schärer, Potter and Hurni, 1992a; Phatak, 1992; Shennan, 1992). Interplants may have a negative impact on crop growth and subsequent yield by interfering with the soil structure and the availability of nutrients and light for the crop (Nicholson and Wien, 1983; Butler, 1986; Vandermeer, 1989; Wiles *et al.*, 1989). Concern about such competitive interference between the vegetable crop and the interplants has mainly impeded development of interplanting-based production systems (Nicholson and

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[†]This term will be used in the following text to refer to deliberately sown or drilled plant species that interact agronomically with the crop; synonyms are: undersowing, cover crops, intercrops, living mulch (Vandermeer, 1989).

Wien, 1983; Wiles *et al.*, 1989). Attempts to reduce competition between crops and interplants in these systems have focused on mechanical and chemical suppression of mulch growth, screening for less competitive mulches, and variations of mulch sowing dates (Vandermeer, 1989; Wiles *et al.*, 1989, and references therein). Minimising the competitiveness of interplants, however, will also reduce the weed-suppressing capabilities of the interplants. In general, minimising interspecific competition and acceptable weed control both constitute major goals of intercropping systems (Theunissen, 1994).

Leek, *Allium porrum* L. is one of the economically most important field vegetable crops in Europe (Hill, 1987; Anonymous, 1990; Benoit and Ceustemans, 1990; Meyer and Kessler, 1990; Benoit and Ceustermans, 1994). It is especially vulnerable to weed interference and nutrient leaching due to its relatively long vegetation period, and its open canopy up to harvest.

The aim of this study was to evaluate the potential of interplanting ryegrass (*Lolium perenne* L. var. Elka) in winter leek (harvested in spring) as an environmentally advantageous alternative to conventional production on bare soil, that generally demands extensive herbicide use (Wallace and Bellinder, 1992). Emphasis will be given to the effects of interplants on (a) weed suppression, (b) the potential to retain soil nitrogen during autumn and winter, (c) the allocation of fertiliser, and (d) crop yield and quality.

Materials and methods

Description of field sites and experimental design

Two parallel experiments were carried out in 1992 and 1993 at two field sites, 'Sandhof' (sandy loam and 2–3% organic matter) and 'Grüntal' (stony, sandy-clayey loam and 2% organic matter). The two sites are 1 km away from each other in Wädenswil (231.050/693.150) near Zürich, Switzerland. Five treatments were arranged in a randomised block design. A weed-free control and two sowing dates of the ryegrass, *L. perenne* var. Elka, were used. Both ryegrass treatments were performed with and without row-application of a herbicide to further assess the effect of the ryegrass on competition with the leek, and on interference with mechanical harvesting (*Figure 1*). Each treatment was replicated 4 times (blocks) resulting in 20 plots, each 1.5 × 5 m (Sandhof) or 1.5 × 4 m (Grüntal). In addition, a split-plot design was established in spring, *c*.6 weeks before harvesting to study the potential of increased fertiliser doses to prevent possible yield reductions through nutrient competition, when ryegrass is used.

Crop and treatment data

Winter leek, *A. porrum* L. cv Blizzard was planted on 4 August 1992 in 3 rows per bed (50 cm apart) and at a distance of 18 cm within the rows. Base-fertilisation was carried out according to soil analyses prior to planting with ammonium-sulfate (Sandhof) and ammonium-Mg-nitrate (Grüntal) to reach 100 kg N/ha before planting. On 18 September 40 kg N/ha was applied in all plots as top dressing. On 25 March, i.e. 6 weeks before harvest, each plot was divided into two sub-plots, which received either the full fertiliser treatment (based on conventional production) or increased fertiliser treatment, i.e. 1.5 times this amount, resulting in 40 and 60 kg N/ha, 60 and 90 kg K_2O/ha, and 12 and 18 kg Mg/ha, respectively. No insecticides or fungicides had to be applied. On 4–6 May 1993, 9 months after planting, the leek was harvested.

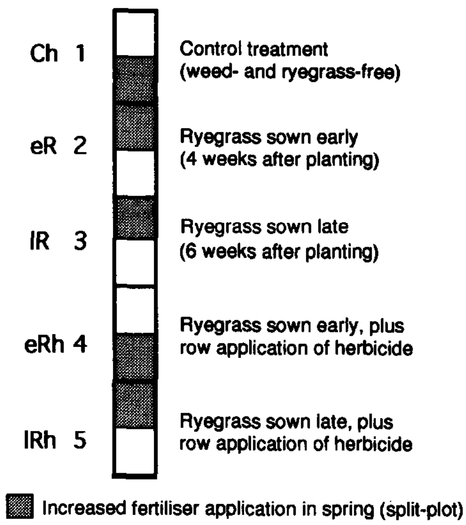

Figure 1. Experimental design of block 3, showing the arrangement of the five treatments (plots) and the split-plots (cf text for details)

Ryegrass (7 g/m^2) was sown evenly over the whole plots on 2 September (early, i.e. 4 weeks after planting) and on 29 September (late, i.e. 6 weeks after planting). This allowed for 1 and 2 mechanical weed control treatments (using an interrow cultivation implement combining a band sprayer and a steerage hoe) before sowing, respectively. Commercially available methazol (75% a.i.) was applied to the crop rows of the control and herbicide plots (treatment 1, 4 and 5, cf. *Figure 1*) in a band of 13 cm, and in two splits on 18 August (1.5 kg/ha) and 27 August (2.5 kg/ha). The inter-rows of the control plots were kept weed-free by hand-weeding.

Measurements

Percent soil coverage of ryegrass and individual weed species was assessed for each plot on five dates in 1992 (17 August, 1 September, 21 September, 14 October and 4 November) and on 2 dates in 1993 (15 March and 29 April). Crop development was monitored by regularly measuring maximum shoot diameter of the same 10 leek plants/plot selected from the middle row. Final measurements at harvest were taken at the sub-plot level, and 10 leek plants of the middle row of each sub-plot were selected. Mineralised nitrogen content of two soil depths (0–30 cm and 30–60 cm; each 5 samples/plot or sub-plot were combined for one measurement) was analysed according to the N_{min} method of Scharpf (1977) on four dates, i.e. after planting, before over wintering, in spring before the application of the fertiliser, and at harvest.

At harvest, the 10 leek plants of the middle row of each sub-plot were removed, and the following variates assessed: total and marketable (after cleaning) fresh weight, shoot diameter, and length of white-coloured shaft (as a quality parameter). Yield per area was calculated by multiplication of the number of leek plants/sub-plot and the mean fresh weight (after cleaning) of the 10 sampled leek plants. Only leek plants conforming to first quality were considered. The ryegrass including the weeds was cut at the soil level in two sample areas of 20 × 20 cm/sub-plot, each one randomly selected in the two inter-rows, and the dry weight and water content was determined after drying for three days at 65°C. Similarly, water content and dry weight for a sample of each 3 leek plants/sub-plot was determined for 6 selected sub-plot treatments. Later, the nitrogen concentration and the C/N ratio of the ryegrass and the leek samples were measured with a CHN-analyser (Heraeus). Thus, a nitrogen balance for these selected sub-plot treatments could be established, which specifically allowed the study of allocation of the 20 kg N/ha applied in surplus in spring. Although the nitrogen content was determined with different analytical methods, and only the N-content in the plants and the soil layer down to 60 cm was assessed, comparison of relative amounts is possible.

Statistical analysis

As all weed pressure, leek performance variates and crop yield markedly differed between the two sites, the two experiments were analysed separately as a split-plot design with the blocks as the repetition factor using analysis of variance (ANOVA) based on the 20 plot means and the 40 sub-plot means, respectively, to avoid pseudo-replications. Hence, treatment factors were tested at the plot level described by the block by treatment interaction term.

Results

Development of ryegrass and weed cover

Mechanical weed control treatments prior to ryegrass sowing removed a considerable portion of the germinated weeds. At the Sandhof site, differences in weed cover between the early and late sowing date of the ryegrass were significant up to mid October ($P < 0.05$), but did not differ before over-wintering (*Figure 2*). By this time, the ryegrass cover in the late sown plots had reached less than half that of the early sown plots, and this difference was maintained over the winter till mid-March. At harvest total coverage (including weeds) of all ryegrass treatments had nearly reached 100%. Weed cover ranged from 20–40%, and was slightly lower in the early ryegrass treatment. In the control plots, weed coverage was kept below 5% by hand-weeding. Within-row coverage by ryegrass and weeds was below 5% in 1992 in the plots with herbicide application and reached a maximum of 20% in spring 1993. In the herbicide-free ryegrass plots, however, coverage at harvest reached 85 and 50% in the early and late ryegrass treatment, respectively.

Early sowing of the ryegrass resulted in a significantly higher biomass production of the interplants (ryegrass

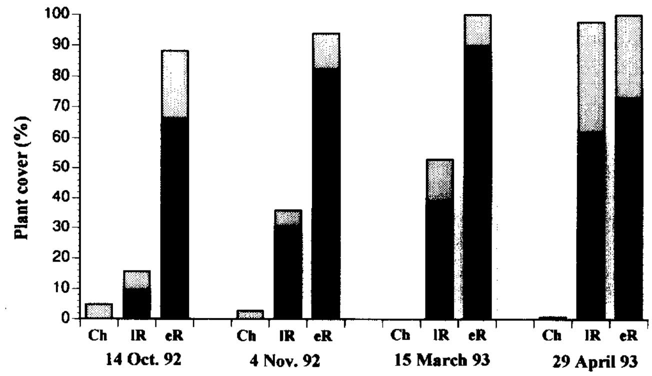

Figure 2. Effect of the sowing date of ryegrass on development of ryegrass and weed cover for the Sandhof site (treatments as in Figure 1: C: control, R: Ryegrass plots, with the ryegrass sown early (e) or late (l), i.e. 4 or 6 weeks after planting; h: row-application of herbicide; ▒ weeds, ■ ryegrass)

and weeds), and the row-application of the herbicide reduced interplant biomass per plot (*Table 1*). Increased fertiliser treatment did not significantly affect biomass of the interplants, but increased nitrogen content and reduced the C/N ratio. Treatment effects on performance variates of the interplants showed similar trends at the Grüntal site, but values were consistently lower (see below).

Important weed species at the Sandhof site were: *Chenopodium album* L., *C. polyspermum* L., *Stellaria media* L. (VILL.), *Capsella bursa-pastoris* (L.) Medikus, *Lamium purpureum* L., *Senecio vulgaris* L., *Galinsoga ciliata* (RAFIN.) BLAKE and *Poa annua* L. The weed composition was similar in Grüntal, but *G. ciliata* was replaced by *Cerastium glomeratum* THUILL. No significant treatment effects on species numbers were observed. At the Sandhof, *G. ciliata* was most abundant in 1992, accounting for the slightly increased weed cover in the early ryegrass treatments in mid October (*Figure 2*), whereas *S. media* and *C. bursa-pastoris* dominated in spring 1993.

Nitrogen content in the soil and allocation to leek and the interplants

After base-fertilisation, absolute amounts of soil nitrogen were similar between treatments and sites, ranging from 210–240 kg N/ha (0–60 cm soil depth). Before the winter (11 November 1992), soil nitrogen content in the early ryegrass plots was reduced to *c*. 30 kg N/ha, as compared to 50–60 kg in the late ryegrass and control plots, reflecting the increased biomass production of the early sown ryegrass. By mid March, nitrogen content again was similar and low (*c*. 25 kg N/ha) in all treatments. Hence, over the winter, little change occurred in the early sown ryegrass plots, but N-losses were considerable in both the control and the late-sown ryegrass plots (*Figure 3*), 32–43 kg N/ha at the Sandhof site and 21–30 kg N/ha at the Grüntal site. In order to study allocation of the soil nitrogen, a simple nitrogen balance (based on soil area) was established for some selected treatments of the Sandhof site (*Figure 4*). In the plots with the standard amount of fertiliser applied in spring, overall amount of

Table 1. Effect of various interplanting treatments with ryegrass in winter leek on interplant (ryegrass and weeds) performance at harvest (Sandhof)

Anova table		Interplants (ryegrass and weeds) dry weight/ sample (g/0.08 m²)	plot (g/10 m²)	nitrogen content (%)	C/N ratio
Split plot design with 5 treatments and 4 blocks (=replicates)					
Source of variation	df				
Block	3	ns	ns	ns	ns
Treatment	4	***	***	ns	ns
Fertiliser	1	ns	ns	*	**
Treatment by Fertiliser	4	ns	ns	ns	ns

Table of means

Treatment	Weed control between rows	Weed control in rows	Fertiliser split-plot	Treatment means (at the plot level) followed by the same letter are not significantly different at the 5% level (Fisher's Protected LSD)			
C	mechanical	herbicide	normal	0.0	–	–	–
C†			high	0.0	–	–	–
lRh	late sowing	herbicide	normal	14.7 a	1360 a	2.845 a	15.41 a
lRh†			high	16.1	1487	3.14	13.91
lR	late sowing of ryegrass		normal	14.3 a	1784 a	2.887 a	15.18 a
lR†			high	15.0	1872	3.017	14.43
eRh	early sowing	herbicide	normal	23.7 b	2188 b	2.857 a	15.56 a
eRh†			high	29.9	2763	3.128	14.12
eR	early sowing of ryegrass		normal	27.3 b	3406 c	2.87 a	15.55 a
eR†			high	29.1	3638	3.155	13.76

ns, not significant; $^*P < 0.05$; $^{**}P < 0.01$; $^{***}P < 0.001$
†increased fertiliser treatment (cf. text)

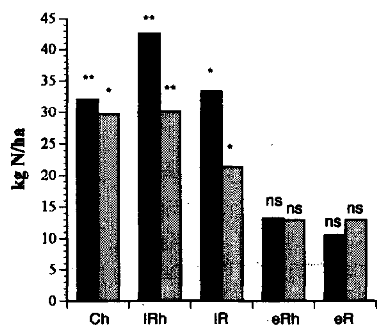

Figure 3. Losses of soil nitrogen content over the winter (11 November–15 March). Significance levels of the differences between the two dates are given for each treatment ($^{**}P < 0.01$, $^*P < 0.05$, ns, not significant). Treatments as in Figure 1: C: control, R: Ryegrass plots, with the ryegrass sown early (e) or late (l), i.e. 4 or 6 weeks after planting; h: row-application of herbicide; ■ Sandhof site; ▒ Grüntal site

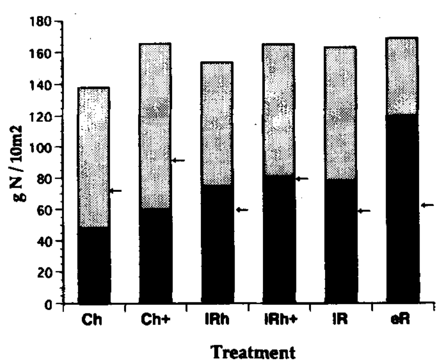

Figure 4. Nitrogen content of the various components of the leek production system at harvest for the Sandhof site (treatments as in Figure 1: C: control, R: Ryegrass plots, with the ryegrass sown early (e) or late (l), i.e. 4 or 6 weeks after planting; h: row-application of herbicide; + indicates treatments with increased fertiliser dose in spring; ■ lower soil, 30–60 cm; □ upper soil, 0–30 cm, ■ interplants (ryegrass and weeds); □ leek; ← available nitrogen after fertilisation in spring

nitrogen per area at harvest was highest in the early ryegrass plots, followed by the late ryegrass and the control plots. The fertiliser effect of the split-plot treatment on total N/ha was not significant. Soil nitrogen content per area was significantly higher in the control treatments as compared with the ryegrass plots ($P < 0.05$), and allocation of nitrogen to the ryegrass mainly occurred at the expense of the N-content in the upper soil. Hence, the largest amount of plant-stored nitrogen (crop, ryegrass and weeds) was reached in the early ryegrass treatment (eR), but only one third of it, i.e. the lowest absolute amount, was allocated to leek. Here, biological storage of the nitrogen in the interplants apparently resulted in reduced allocation to the crop. Amount of nitrogen in leek was similar in the late ryegrass treatments, and the control with normal rate of fertiliser, and highest in the control treatment with increased fertiliser dose.

Allocation of the surplus 20 kg N/ha applied in spring at the sub-plot level was further analysed for the control and the late, herbicide-free ryegrass treatments of both sites. This was done by comparing differences between the values of each of the two corresponding sub-plots. The results again indicate, that the additional nitrogen mainly was stored in the interplants, and not in the leek (*Figure 5*). Available nitrogen in spring was higher, and the effect of the additional fertiliser was stronger in the control plots. Hence, in the control plots, the amount of nitrogen allocated to leek could be increased by the additional fertiliser. In the ryegrass plots, however, such surplus amounts of fertiliser – intended to counteract possible yield reductions in the ryegrass plots due to nutrient competition – was found to only slightly increase, or even reduce N-allocation to leek when overall soil nitrogen levels were low. This trend was more pronounced at the Grüntal site, where available nitrogen after spring fertilisation was lower (*Figure 5*).

Growth development of the leek

Growth development of the leek, given as increase in shoot diameter, is shown in *Figure 6* for both sites. Increase in growth in autumn and spring each directly followed top applications of fertiliser. At both sites, growth curves substantially diverged during the last 50 days before the harvest. During this period, linear increase continued in the control plots, whereas the leek in the ryegrass plots remained constant or even slightly decreased. This may indicate severe growth limitations in the ryegrass plots before harvest. Late

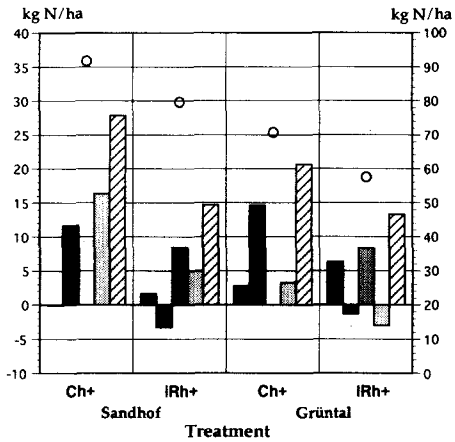

Figure 5. Nitrogen allocation of surplus fertilisation in spring with 20 kg N/ha for two selected treatments. Treatments as in Fig. 1: C: control, R: Ryegrass plots, with the ryegrass sown late (l), i.e. 6 weeks after planting; h: row-application of herbicide; *left axis*: ■ lower soil, 30–60 cm; ■ upper soil, 0–30 cm, ■ interplants (ryegrass and weeds); leek; ▨ total of plant and soil (0–60 cm) nitrogen; *right axis*: ○ available nitrogen after fertilisation in spring

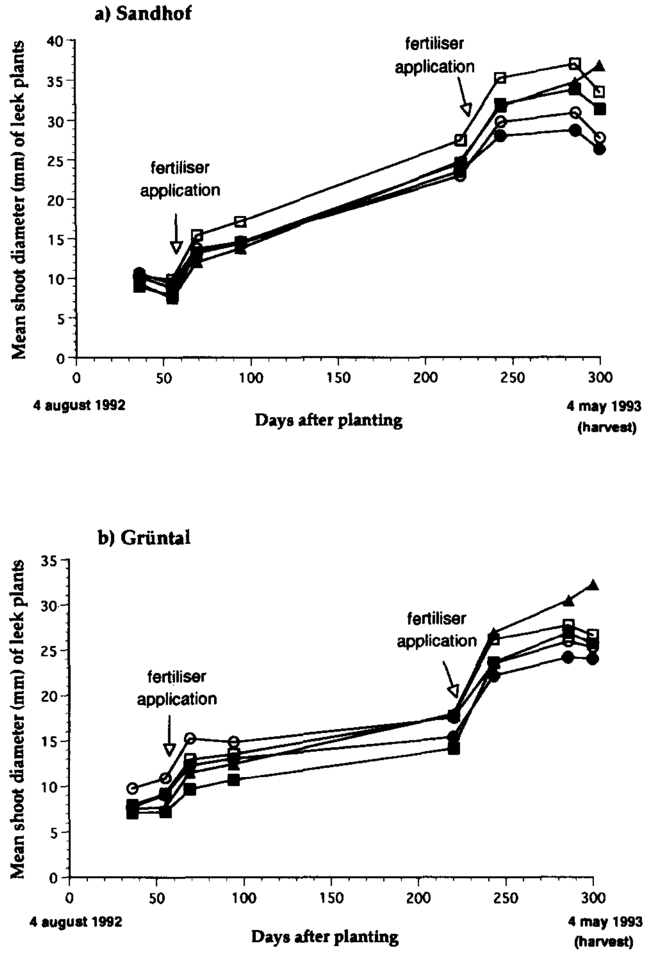

Figure 6. Growth development of leek. Treatments as in Figure 1; ▲ Ch, ○ eR, □ lR, ● eRh, ■lRh; C: control, R: Ryegrass plots, with the ryegrass sown early (e) or late (l), i.e. 4 or 6 weeks after planting; h: row-application of herbicide

Table 2. Effect of various interplanting treatments with ryegrass in winter leek on leek performance at harvest (Sandhof)

Anova table

Split plot design with 5 treatments and 4 blocks (=replicates)		Average leek plant fresh weight/ total (g)	fresh weight/ marketable (g)	stem length (cm)	stem width (mm)	white stem (cm)	nitrogen content (%)	C/N ratio	water content (%)
Source of variation	df								
Block	3	ns	ns	ns	ns	ns	ns	ns	ns
Treatment	4	**	**	***	***	*	*	*	*
Fertiliser	1	ns	ns	ns	ns	ns	ns	ns	ns
Treatment by Fertiliser	4	ns	ns	ns	ns	ns	ns	ns	ns

Table of means

Treatment	Weed control between rows	Weed control in rows	Fertiliser split-plot	Treatment means (at the plot level) followed by the same letter are not significantly different at the 5% level (Fisher's Protected LSD)							
C	mechanical	herbicide	normal	348.7 b	234.3 b	13.9a	36.7 c	4.7a	1.9 c	22.3a	86.4 b
C†			high	372.1	251.5	14.7	37.0	5.3	2.1	21.8	86.9
IRh	late sowing	herbicide	normal	311.0ab	197.3ab	16.3 b	31.2 b	6.1ab	1.7 bc	25.5a	85.8 b
IRh†			high	315.5	197.8	16.1	32.1	5.8	23.2	86.3	
IR	late sowing of ryegrass		normal	364.8 b	239.4 b	16.9 b	33.3 b	7.9 b	1.6 b	26.5a	86.0 b
IR†			high	350.8	235.0	16.4	32.5	6.8			
eRh	early sowing	herbicide	normal	234.3a	159.6a	16.0 bc	26.2a	6.8 b			
eRh†			high	255.1	156.3	17.6	26.1	6.4			
eR	early sowing of ryegrass		normal	253.4a	166.6a	17.9 c	27.7a	6.8 b	1.2a	35.1 b	84.2a
eR†			high	256.0	178.0	17.8	26.7	7.8			

ns, not significant; $*P < 0.05$; $**P < 0.01$; $***P < 0.001$
†increased fertiliser treatment (cf. text)

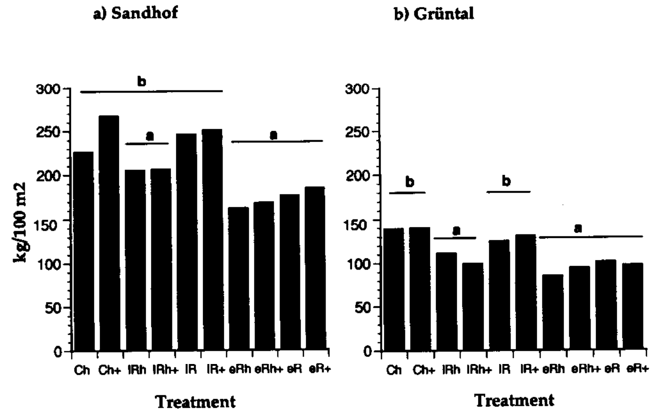

Figure 7. Marketable yield of leek. Treatments as in Figure 1, C: control, R: Ryegrass plots, with the ryegrass sown early (e) or late (l), i.e. 4 or 6 weeks after planting; h: row-application of herbicide; + indicates treatments with increased fertiliser dose in spring. Treatments (double columns) with the same letter are statistically not different at the 5% level (ANOVA, Fisher's Protected LSD)

ryegrass treatments tended to produce thicker shoots as compared with plants subjected to early ryegrass sowing.

Performance variates of the leek

Early ryegrass (eR, eRh), as compared to clean controls considerably reduced some performance variates measured for leek, such as fresh weight and weight after cleaning (marketable weight), shaft width and nitrogen and water content, while other variates were increased, like height and white-coloured portion of the shaft (*Table 2*). Values of the late ryegrass treatment ranged between these two treatments, but often were not significantly different from the controls. Surprisingly, fresh weight was decreased in both ryegrass treatments, when the leek row was kept clean by herbicides. Increased fertiliser application 6 weeks before harvest had no significant impact on any of these leek variates (*Table 2*).

Crop yield (marketable fresh weight per area)

The presence of ryegrass, and the additional fertiliser treatment in spring, did not significantly affect the number of surviving (harvested) leek plants per subplot. Hence, treatment effects on crop yield were similar to the mean fresh weight data of individual leek plants (*Table 2* and *Figure 7*). In both experiments, crop yield of the late ryegrass plots (at the Grüntal site only the herbicide-free treatment) was similar to the control and significantly higher than of the early ryegrass plots (*Figure 7*).

Discussion

Weed suppression by the ryegrass

The rational to sow the ryegrass not directly after planting, but 4 or 6 weeks later, was both to allow for one and two mechanical weed control treatments, respectively, prior to sowing, and to prevent severe competition with the leek (Butler, 1986; Wiles *et al.*, 1989; Matthäus and Jampen, 1991). The mechanical control treatments were most effective, especially at the Sandhof site, where weed pressure was high, mainly caused by the summer annual *G. ciliata*. Weeds most harmful in vegetable crops are those competing for light, i.e. tall and fast growing plants with a large biomass, such as *Amaranthus* species. None of those caused severe problems in spring, although they were present at both sites. Thus, the combined effect of the mechanical weed control treatments and the ryegrass resulted in sufficient weed suppression. Seed set up by some of the weed species, however, may well occur before harvest.

Impact of the ryegrass on nitrogen cycling

Organic growers look to interplants as an important component of fertility management and efficient nutrient cycling. The incorporation of the interplant biomass into the soil further provides additional organic matter input, which in turn also may lead to improved physical properties and water infiltration characteristics (Shennan, 1992). Other vegetable producers are mainly interested in cover crops to reduce leaching losses of nutrients, and thus to minimise ground water contamination (Muller, Markt and Mariotti, 1987; Power and Schepers, 1989). Vegetable production usually involves high inputs of N, which makes these production areas particularly sensitive to nitrate leaching. In addition, nitrogen levels in autumn are often unavoidably increased due to both abiotic and biotic conditions (increased soil temperatures, soil ventilation through cultivation, N-mineralisation, etc.) (Hogue and Neilsen, 1988). Results, prospects and limitations of cover crops on nitrogen cycling and soil properties in vegetable production systems recently have been summarised by Shennan (1992). She cites, for example, Martinez and Guiraud (1990), who found in a lysimeter study in France, that Italian ryegrass (*L. perenne* L.) reduced leaching losses from 110 kg N/ha under bare fallow to 40 kg N/ha. In our study, effects were less pronounced, but the results indicate that in the ryegrass plots, part of the observed losses in soil nitrogen during autumn and winter apparently were allocated to the interplants, and thus retained from being washed out. In the control plots, the greater portion, i.e. approximately 20 kg N/ha – well corresponding to the difference in total nitrogen per area between the control and the late ryegrass treatment – most possibly has been washed out. In the late ryegrass treatment (lR), above-ground biomass production of the interplants reached 1784 kg/ha (*Table 1*), with a total N-accumulation of *c.* 50 kg N/ha. After the harvest, the ryegrass was mulched and incorporated into the soil with a spading cultivator. High soil temperatures and rainfall in the spring generally provide favourable conditions for rapid decomposition. Both N-mineralisation and nitrification have been found to occur rapidly, as shown by a brief peak in soil ammonium levels within 10–15 days after incorporation, followed by a rapid increase in soil nitrate (Shennan, 1992).

Impact of the ryegrass on crop yield and quality

Yield of leek was consistently lower at the Grüntal site, which can be explained by reduced amounts of nitrogen (and possibly also other nutrients) available in spring 1993 (*cf. Figure 5*). At both sites, the late, herbicide-free ryegrass treatment resulted in crop yield similar to the corresponding control treatment. Most possibly through light interference, qualitative yield parameters, however, were increased. Leek plants growing with late sown ryegrass were taller, thinner, showed an increased white-coloured portion of the shaft and a reduced nitrogen content as compared with controls. Such plants generally are preferred by the market (F. Keller, pers. commun.).

The early ryegrass treatment resulted in severe yield reductions, and the effect on leek quality found in the late ryegrass treatment were further increased. Yield reduction in the late ryegrass treatments through row-application of the herbicide was unexpected, as this treatment was intended to reduce immediate competition with the leek. A possible explanation seems to be a direct negative impact of the herbicide on leek growth. Methazol was applied at a rate exceeding the recommended dose of 3 kg/ha, mainly to control the already well established *G. ciliata*. Although applied in two split doses, such amounts of the systemically acting methazol apparently have been observed to reduce growth development of some leek varieties, including the one used in our experiments (D. T. Baumann and J. P. Mayor, pers. commun.). As the increased fertiliser dose in spring further improved crop yield in the control plots, total amount of fertiliser may have been too low at the Sandhof site. In order to better direct the fertiliser to the leek in the ryegrass plots, application of additional fertiliser will have to be restricted to the crop rows.

Interference of ryegrass with harvesting

At harvest, the soil was undercut and the leek removed by hand (half-mechanical harvest). This was easiest in the control treatment, where the leek plants efficiently could be collected, but similarly difficult in all ryegrass treatments. Here, full mechanical harvest, where leek plants are picked up automatically, may lead to losses through breaking off the shafts, entangled with ryegrass roots. When leek plants are picked up by hand, impediment was estimated to be tolerable, but this may greatly depend on soil conditions at harvest.

Prospects and limitations of interplanting ryegrass in leek

When environmentally friendly cropping methods have to be developed, and maximum yield is no longer the ultimate goal in agriculture, application of interplanting-based production systems undoubtedly have many advantages in the vegetable agroecosystem, mainly by increasing biodiversity, i.e. through diversification of the habitat (Phatak *et al.*, 1991; Phatak, 1992; Shennan, 1992; Wallace and Bellinder, 1992; Theunissen, 1994). A previous experiment with autumn (harvested) leek showed that when ryegrass *L. perenne* var. Elka was intersown 5 weeks after planting, crop yield was similar to chemically treated clean plots (Müller-Schärer, Potter and Hurni, 1992a,b). Weeds, that germinated after the two mechanical weed control treatments applied prior to ryegrass sowing, were suppressed sufficiently. Ryegrass further significantly reduced attack by thrips (Thysanoptera: *Trips tabaci* Lind.) and increased nitrogen retention in the soil during autumn and winter. At harvest, the soil was undercut, the leek removed and the detached grass pressed back on the soil with a roller. Due to this treatment, a well established grass cover remained alive during autumn and winter.

Brakeboer (1991) recently reported on experiments with various interplants in leek mainly to reduce pathogen infestations. All the species used, including *L. perenne*, reduced *Phytophtora* infestations on leek and further protected the crop against frost.

In the present experiment, intersowing ryegrass 6 weeks after planting, resulted in similar yield to the clean controls. However, crop quality was increased and overall, leek production was environmentally more advantageous. Seed production of the weeds, harvesting impediments, seed costs of the ryegrass and additional farming operations involved in the establishment and incorporation of the interplants are some of the constraints and potential negative impacts of the system elaborated so far. Interplanting makes vegetable growing more complicated and more knowledge and skills are needed to optimise production (Theunissen, 1994). In order to make such systems operational in commercial vegetable growing, and to overcome the presently high risk aversion of the farmers, further research and economically acceptable solutions are needed. Interplanting-based production systems constitute, however, an important step forward to a more diverse and sustainable agriculture.

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