DISSERTATION

LEGUME-WHEAT ROTATION IN DRYLAND CROPPING SYSTEMS IN EASTERN COLORADO

Submitted by
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WE HEREBY RECOMMEND THAT THE DISSERTATION PREPARED UNDER OUR SUPERVISION BY HUGO R. KRUGER ENTITLED LEGUME-WHEAT ROTATION IN DRYLAND CROPPING SYSTEMS IN EASTERN COLORADO BE ACCEPTED AS FULFILLING IN PART REQUIREMENTS FOR THE DEGREE OF DOCTOR OF PHILOSOPHY

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ABSTRACT OF DISSERTATION

LEGUME-WHEAT ROTATION IN DRYLAND CROPPING SYSTEMS IN EASTERN COLORADO

In the Great Plains of the United States, hard red winter wheat (*triticum aestivum L*) is the dominant dryland crop. A fallow period of approximately 14 months is used to increase soil water storage and enhance yield. This technique has a low precipitation storage efficiency and produces soil degradation. Thus, replacing part of the summer fallow by a crop can increase the water use efficiency of the system.

Legumes are interesting because of their forage and grain production, and their potential N input for the subsequent crop. Four legume cultivars: Austrian winter pea (*Pisum sativum L. var. arvense*), Profi pea (*Pisum sativum L.*), and two soybeans (*Glycine max. L. Merr*), were grown during the spring and summer previous to a wheat crop during 1998, 1999 and 2000 in eastern Colorado. The objectives were: a) to evaluate their forage and grain production and their N uptake and water use under three utilization alternatives (forage, grain and green manure), b) to determine their effect on subsequent wheat yield.

Averaged across three years the forage production of Austrian winter pea, Profi pea and soybean was 1873, 831 and 1550 kg ha^{-1}, respectively. Grain yield was 832, 1014, and 1521 kg ha^{-1} for Austrian winter pea, Profi pea, and soybean respectively. The total N returned to the soil after termination of the forage treatment was less than 15 kg ha^{-1}. When used for green manure, the N input was 72 kg ha^{-1} for Austrian winter pea, 29 kg ha^{-1} for Profi pea and 66 kg ha^{-1} for soybean. The N input from the grain management was similar to the green manure treatment. The water use of the legumes depended on the precipitation during the growing period, the dry matter production and the utilization of the legume. In 1999 wheat yield after legumes for forage, grain and green manure was respectively 23, 51 and 29 percent lower than wheat yield after fallow. In 2000, wheat yield did not decrease after legumes for forage, but after legumes for grain and green manure it was respectively 34 and 17 percent lower than after fallow.

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INTRODUCTION

In the Central and Southern Great Plains of the United States, hard red winter wheat (triticum aestivum L.) is the dominant dryland crop primarily because of its high-yielding potential (Greb et al., 1979) with limited crop substitutions (Johnson, 1977).

Water and N availability are two of the most critical inputs in crop production (Hargrove et al., 1988; Nielsen and Halvorson, 1991). Low precipitation and high evaporation potential limit yields of dryland crops. Thus, fallow is used to increase soil water storage and enhance yield. With this practice, no crop is grown during the fallow period, weeds are controlled by cultivation or chemicals to enhance soil-water storage and nutrient availability for the subsequent crop. The fallow period is approximately 14-15 months, extending from wheat harvest in July to the next wheat planting in September of the next year (Norwood and Dhuyvetter, 1993; Faharani et al., 1998; Schlegel et al., 1999).

According to Peterson et al. (1993), the yield stability achieved with the summer fallow practice has been accompanied by several negative features that threaten the sustainability of agriculture: soil erosion, low precipitation use efficiency and loss of soil organic C and N. Evidence of its negative influence on soil and environmental quality continues to build, and even its economic advantage seems to be lessening with the combination of high production costs and low grain market prices (Peterson et al. 1998).

Faharani et al. (1998) have described the so called "paradox of summer fallow", referring to the fact that, "...only a small portion of the precipitation received is stored during fallow, and soil evaporation far exceeds other losses by weeds, volunteer plants, runoff, deep seepage, and snow blow-off". They found that in the west central Great Plains only 20% of the precipitation received during the fallow was stored in the soil profile, and provided similar data from other studies in the region. Mathews and Army (1960) reported an average 16% storage for 25 stations in the Great Plains. Peterson et al. (1996) reviewed several locations and found storage efficiencies of 10% in Texas, 22% in eastern Colorado, 25-30% in Western Canada, and 18-37% in the Northern plains. A comparable phenomenon has also been described in other regions of the world like central Queensland in Australia for wheat production (Armstrong et al. 1999), dryland areas in Israel (Bonfil et al. 1999), and Semiarid Pampas in Argentina for summer crop production (Kruger, 1993).

The development of reduced and no-till practices with proper management of crop residues on the soil surface improved the fallow technique, providing more water storage, better erosion control and improved soil structure (Knowles et al. 1993, Peterson et al. 1998). However, the fallow efficiency improved only from 16 to 25% storage with no-till fallow (Faharani et al. 1998). Lyon et al. (1998), found that grain yields in a winter wheat-fallow rotation in Nebraska did not benefit from the increased soil water storage in no-till plots. Other authors, cited by Dhuyvetter et al. (1996), also reported that decreasing the amount of tillage in wheat-fallow system did not increase yield.

According to Peterson, et al. (1996) there appears to be little possibility of further reducing evaporation by use of surface residue, particularly since residue production in Great Plains dryland agriculture is limited. Planting a spring crop that can utilize both the stored water and the summer precipitation is the key to improving system efficiency. The summer precipitation is used by the crop instead of being lost to evaporation during the summer of fallow (Peterson and Westfall, 1996).

In this way, a new approach known generically as "cropping intensification" attempts to increase the water use efficiency in dryland agriculture by reducing the proportion of summer fallow in the wheat-fallow system and replacing it with summer crops. The gain in efficiency with cropping intensification is not due to enhanced water conservation but to reallocation of water, from evaporation from the soil during the summer of fallow into the transpiration stream of a plant. Thus, the underlying basis for intensification is a partial replacement of soil evaporation with crop transpiration (Farahani et al. 1996).

Under the cropping intensification approach, the 2-year wheat-fallow system may be replaced, for example, by a 3-year wheat-sorghum-fallow rotation. In the wheat-sorghum-fallow rotation, wheat is planted in September and harvested in July. Then, the land is fallowed for approximately 11 months until sorghum is planted in May-June. The sorghum is harvested in October, and followed by another 11 month fallow period after which wheat is planted again (Norwood and Dhuyvetter, 1993).

In the Great Plains, dryland-cropping intensification has increased annualized grain yield and biomass production, soil-surface organic matter, and net returns (Farahani et al. 1998). Since cropping diversification is an integral part of intensification, the search for new crops that can fit into the wheat-fallow system is an important issue for dryland agriculture. Peterson et al. (1996), listed the most common modifications to farming systems in the Great Plains as: a) adoption of cropping systems producing two crops in three years with a 10-11 month fallow preceding each crop, and b) continuous cropping of spring wheat or rotations of spring wheat-sunflower.

Nielsen et al. (1999) investigated the effect of growing sunflower just ahead of winter wheat at Akron, Colorado. They found significantly lower wheat yields during dry years (70% of wheat after fallow), and non-significant differences in yields in years with above-normal rainfall.

Legumes are presently receiving a renewed attention from researchers as an alternative for cropping intensification. Studies reported by Biederbeck et al. (1993) suggested that replacement of fallow with forage, grain or green manure legumes would protect the soil from erosion and degradation and add valuable N for use by the following crops. However, for dryland producers in the Central and Southern Great Plains the cost in water use by the legume is an important consideration. The water use by the legume may deplete surface soil water to the extent that germination and growth of the following grain crop is restricted (Power et al. 1983; Vigil and Nielsen, 1998).

In 1944, Brandon and Mathews stated that green-manure fallow at Akron, CO produced lower yields in the following crop than ordinary fallow, and did not increase the yields of subsequent crops (Willis et al. 1983). Lack of precipitation to replenish the soil water content and high soil fertility were given as reasons for the lack of response to legumes.

Biederbeck and Bouman (1994) in Swift Current (Canada), reported legume water depletion as being confined to the upper 0.6 m of soil when growing under drought, but with high soil water content at planting. In years with low initial water content, however, substantial soil water depletion occurred below 0.6 m. More recently Vigil and Nielsen (1998) in Akron, CO investigated the effects of three green manure legumes (Austrian winter pea, spring field pea and black lentil) and their termination dates on subsequent winter wheat yields in 1994 and 1995. The wheat yields following the legumes were reduced, compared to traditional summer fallow, by 400 kg ha^{-1} at the earliest legume termination dates and by at least 1050 kg ha^{-1} at all other dates. They found that 80% of the variability in subsequent wheat yield was explained by the legume water use the previous year. In this context the earlier termination dates using less water were more adequate, but during dry years their ET was higher than fallow ET. In wet years, with more water in the upper layers of the soil, wheat after fallow had a similar ET to wheat after legumes terminated early in the season. Economic analysis relating the potential benefit of legume N and the cost of the same amount of fertilizer N and the wheat yield depression, indicated that legume N was too expensive in this system, and return during dry years was maximized when legumes are not grown and the land was allowed to be fallowed.

Poss (2001), working in two locations in eastern Colorado found Austrian winter pea to be the best forage legume to grow before wheat when attempting to increase the cropping intensity in the wheat-fallow system. Wheat yield depressions after winter pea were 10% compared to wheat after fallow, averaged across two sites and four years. Yield depressions varied with years, depending on the precipitation from July, after legume growth, through June of the next year. His economic analysis, based on the income from the pea and the cost of average yield depression, showed an advantage for integrating the pea into the cropping system. The net return of a wheat-corn-pea rotation increased by \$14.3 ha^{-1} compared to a wheat-corn-fallow rotation.

Both Poss and Vigil and Nielsen (1998) studied forage legumes in eastern CO, terminated early in the summer and the effect of water use. They showed that in dry summers the water use of the legume was not recovered by precipitation, thus decreasing subsequent wheat yield. Poss found that water infiltration during the high evaporative period after the legume termination was higher than in fallow, with the soil close to field capacity by wheat planting. Vigil and Nielsen (1998) showed that the type of legume was not important related to the effect on wheat yield. However, the three legume studied were similar in growing period, and forage harvest was the only utilization studied.

Based on previous research, it can be hypothesized that the use of a forage legume during the last part of the summer, with average rainfall, but also high evaporative conditions, could use this rainfall more effectively and deplete soil water to a lesser degree (Fig. I.1). Soybean is a potential crop to be grown under these conditions. The fact that, as a legume, can benefit from N-fixation and the availability of Roundup Ready varieties with cheap weed control makes it an interesting crop, still not yet intensively studied in dryland eastern Colorado.

The comparison of soybean production and its effect on winter wheat, related to pea production, should be interesting. If soybean is used for grain production, the water use will certainly be higher than for forage, and the decrease in wheat yield will likely be greater. However, depending on the soybean yield, the grain production could compensate for wheat yield loss and perhaps increase the overall system profits.

Utilization of legumes as green manure would provide no profit in the short term, but a potential for higher water storage after the termination of the legume, and the N input from any amount of N-fixation to the subsequent crop. Poss (2001) reported the N input from Austrian winter pea at harvest as about 70 kg ha^{-1}. Vigil and Nielsen (1998) found as much as 130 kg N ha^{-1}. The benefits of green manuring, however, remain unclear.

The general objective of this study was to evaluate the use of legumes as a replacement for fallow during the spring-summer period before wheat, in eastern Colorado cropping systems. Specific objectives were:

a) Test four legumes cultivars (pea and soybean), under three utilization alternatives (forage, grain and green manure), evaluating their above and below-ground dry matter production, N uptake and water use. Of special interest is the performance of soybean, relative to the more thoroughly studied pea.
b) Determine the effect of these legumes on subsequent wheat yield.

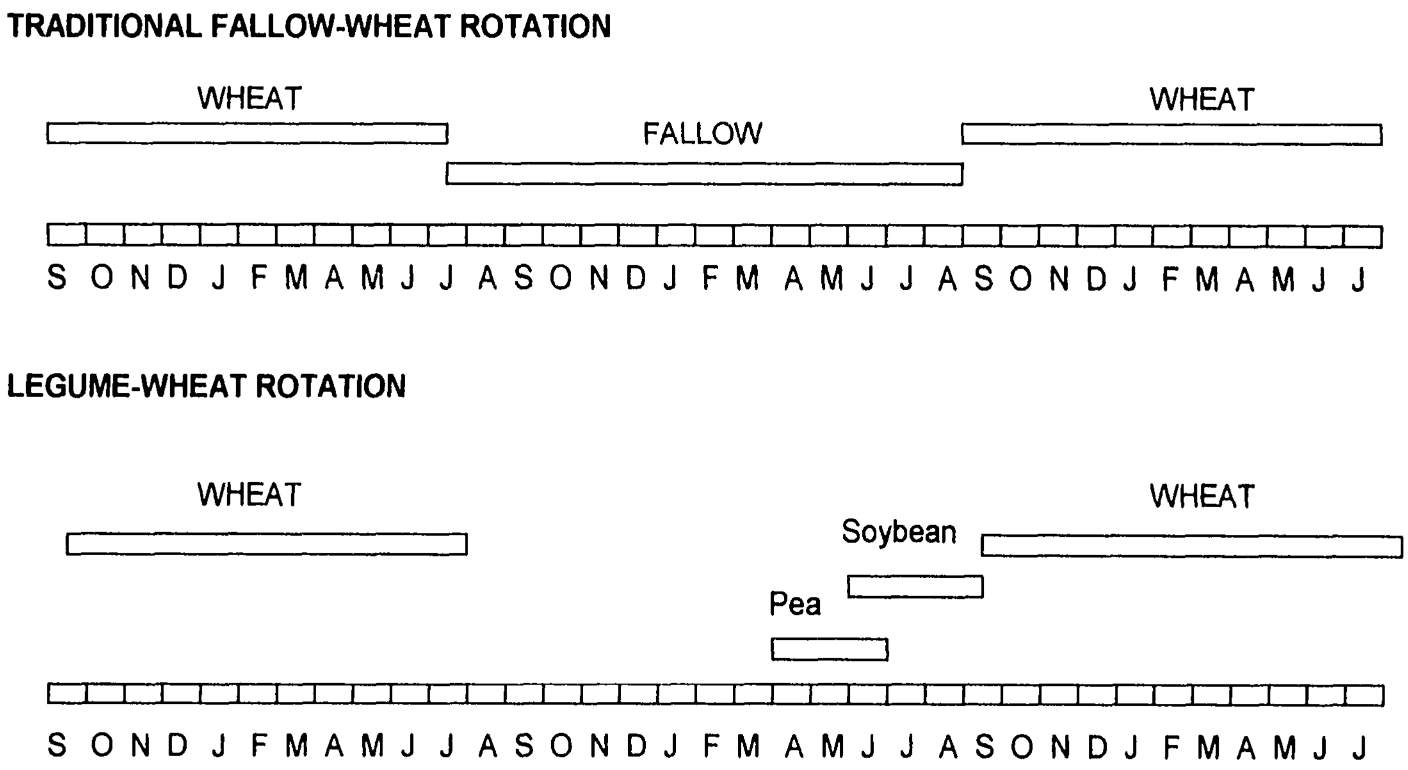


Fig. I.1 – Relative growing periods of wheat and legumes in fallow-wheat and legume-wheat rotations.

Chapter 1

MATERIALS AND METHODS

Three sequences of legume-winter wheat were studied during 1998, 1999 and 2000. Adjacent, but different experimental sites were used for each sequence. The experimental sites were located at 40°09' N latitude and 103° 08' W longitude, on the Central Great Plains Research Station, ARS-USDA and CSU Experimental Station, at Akron in Washington County (Eastern Colorado).

Two soil units were present in the experimental site (U.S.D.A.- S.C.S., 1986): Rago silt loam and Weld silt loam soil series. The Rago soil is classified as a *fine, montmorillonitic, mesic Pachic Argiustoll* was the dominant soil at the 1998 and 1999 sites. The Weld soil, the main soil present at the 2000 experiment site, was classified as a *fine, montmorillonitic, mesic Aridic Paleustoll* . Table 1.1 presents some selected characteristics of the soil at the experimental site in 1998.

Two factors were studied during the legume growing season: Legume species (including a control under fallow), and legume management. The four legume studied were. Two field peas: Austrian winter pea (*Pisum sativum L var. arvense.*), Profi pea (*Pisum sativum L.*), and two soybeans: (*Glycine max. L. Merr*), belonging to maturity groups I, II and/or III, all legumes were planted no-till into a wheat stubble. A control treatment using chemical fallow was also included. In October each year, winter wheat (*Triticum aestivum L.*) was planted no-till into the legume residues as well as into the fallow plots.

Table 1.1 – Selected characteristics of the soil at the experimental site in 1998.

DEPTH cm	Organic C g kg^{-1}	Total N g kg^{-1}	C:N Ratio	$N\text{-}NO_3$ kg ha^{-1}	pH
0-10	9.3	0.9	10.7	12.3	6.4
10-20	7.5	0.9	9.4	8.9	7.3
20-30	—	—	—	11.9	7.6
30-60	—	—	—	27.4	8.2
60-90	—	—	—	14.7	8.7
90-120	—	—	—	14.6	8.8

The management factor included three termination times: a) Forage: the legumes were harvested for forage at full bloom stage. b) Green Manure: the legumes were killed with herbicide at the time of forage harvest and the plants remained on the soil as a cover. c) Grain: the legumes were harvested for grain at physiological maturity.

The legume species factor involved two different plant characteristics and growing periods (spring-early summer for the peas and summer-early autumn for the soybeans). This creates a potentially different utilization of soil and rainfall water, and different possibilities for refilling the soil water profile after the legume crop. Although the legumes used were not specifically suitable for all the management levels studied, the objective of this factor was to obtain information about the relative impact of the different legume utilization strategies on the subsequent wheat crop.

The management factor involved different growth length periods for the same crops (with consequences on soil and rainfall water utilization), and different soil cover situations after the legume, which could affect soil water profile refill before wheat, and potential N availability from the legume residues and roots.

During the growth of the winter wheat crop, a third factor, N fertilizer, was added with two levels: no N fertilizer (0N), and 40 kg N ha^{-1} (40N). To evaluate the wheat response to N after the legumes, only in the Austrian winter pea plots, two extra levels were used in order to have 0, 20, 40 and 60N rates.

Agronomic practices

The pea and soybean were planted in the spring the first year of study. Austrian winter pea was planted in fall the subsequent years. A John Deere No-Till Maxi-merge planter with disc openers (0.3 m between rows), was used the first year for all legumes; a Tye No-Till drill with double disk openers (0.2 m between rows), was used for Profi pea and soybean the rest of the years. Table 1.2 shows the corresponding dates and seed rates used during the study.

All legumes were harvested for forage at the late bloom stage in the corresponding management levels (Table 1.2). The forage was measured and removed from the plots. The pea in the green manure treatments were killed using a mixture of 2,4- D and glyphosate herbicides (LandMaster). An application of 2,4- D was used to kill the Roundup Ready soybeans. After forage and grain harvest the legume plots weeds were controlled with LandMaster. Hard red winter wheat was planted after the legumes on fall, with two different levels of N fertilizer applied on the soil surface over the seed row. Only the wheat after Austrian winter pea had four N rates (Table 1.2). The weed population was monitored in the wheat during spring, but no herbicide was needed due to low infestations. The wheat data for the last sequence are not available at this writing date.

Measurements

Daily rainfall and air temperature data were collected during the experiment period using an automatic meteorological station located at the nearby Experiment Station within 1 km of the experimental site.

Soil water content was determined to the 0-120 cm depth using a neutron probe, with readings for each 30 cm increment. The readings were corrected using a calibration equation developed with soil samples taken during the access tube installation and using the standard gravimetric method as a control. The regression calibration equation and statistics are presented in Table 1.3. Bulk density data, for nutrient and water conversion to a volume basis, were obtained from core samples taken during the installation of the neutron probe tubes.

Table 1.2 – Planting and harvesting dates, varieties, and seed and fertilizer rates used during the experiment.

	YEAR		
	1998	1999	2000
		Austrian winter pea	
Planting Date	04/30/98	10/13/98	10/14/99
Seed Rate (kg ha^{-1})	90	106	134
Fertilizer	no	no	no
N Rate (kg ha^{-1})	---	---	---
Forage Harvest Date	07/17/98	06/14/99	06/19/00
Grain Harvest Date	07/29/98	07/16/99	07/13/00
		Profi pea	
Planting Date	*4/30/98	03/26/99	03/29/00
Seed Rate (kg ha^{-1})	58	134	160
Fertilizer	no	no	no
N Rate (kg ha^{-1})	---	---	---
Forage Harvest Date	07/17/98	06/14/99	06/14/00
Grain Harvest Date	07/29/98	07/27/99	07/13/00
		Soybean	
Planting Date	05/26/98	05/19/99	05/30/00
Varieties	Asgrow 1901 Asgrow 2301	Asgrow 2001 Asgrow 2301	Asgrow 2602 Asgrow 3901
Seed Rate (kg ha^{-1})	67	67	57
Fertilizer	no	no	no
N Rate (kg ha^{-1})	---	---	---
Forage Harvest Date	08/12/98	07/27/99	08/15/00
Grain Harvest Date	09/20/98	09/23/99	09/30/00
		Wheat	
Planting Date	10/13/98	10/14/99	10/17/00
Varieties	Halt	Halt	Prairie Red
Seed Rate (kg ha^{-1})	67	100	100
Fertilizer	UAN 32% (1)	UAN 32% (1)	UAN 32%
N Rate (kg ha^{-1}) (2)	0N = 7 40N = 46	0N = 7 40N = 46	0N = 0 40N = 48
Forage Harvest Date	no	no	no
1st Biomass Sampling	04/20/99 to 05/14/99	04/17/C0	---
Grain Harvest Date	07/12/99	07/05/00	---

(1) Plus Ammonium Polyphosphate (10-34-0)
(2) Only after Austrian winter pea, two additional N rates were: 20N=22 kg N ha^{-1}, 60N=67 kg N ha^{-1} in 1998 and 1999, and 20N=28 kg N ha^{-1}, 60N=74 kg N ha^{-1} in 2000.

Table 1.3 - Calibration for neutron probe readings at the experimental site

Analysis of Variance Table

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	1	182471	182471	251.15	<.0001
Error	43	31241	726.54		
Corrected Total	44	213712			

Root MSE	26.954	R-Square	0.8538
Dependent Mean	230.355	Adj R-Sq	0.8504
Coeff Var	11.701		

Parameter Estimates

Variable	DF	Parameter Estimate	Standard Error	t Value	Pr > |t|
Intercept	1	-16.585	16.092	-1.03	0.3085
grav (mm 30 cm^{-1})	1	3.514	0.222	15.85	<.0001

Regression equation

mm 30 cm^{-1} = 4.72 + 0.285 * (neutron probe counts)

According to Ratliff et al. (1983), field measurements are more accurate than laboratory-estimated soil water limits. However, the period of field measurements in this study was relatively short and some of the soil layers did not meet the definitions for the lower and higher limits provided by Ratliff et al. For these reasons soil water values based on textural classes (M. Vigil, personal communication) were used as reference values in the interpretation of results.

Above-ground biomass samples were obtained regularly (2-3 weeks) during the legume growing season, starting at about 50 days after planting. The composite samples (4 sub-samples per plot) were collected by cutting the plant stems 1 cm above the soil surface from a total area of 1.2 m^2 (in the 0.3 m spaced rows), and 0.8 m^2 (in the 0.2 m spaced rows).

Below-ground biomass samples were collected a few days before forage harvest (late bloom stage). Two 0.1 m diameter cores per plot were taken at two depths: 0-18 cm and 18-36 cm. The core samples were driven into the soil side by side, covering the row and one inter-row space at each depth. The legume roots were carefully removed by hand from the core, washed with distilled water and oven-dried at 60°C. They were then weighed and ground for total C and N analysis using a LECO™ instrument.

The root biomass data were separated into taproots, thin roots, and nodules in the row core. For the N and C content determinations, samples from different blocks were combined from the 18-36 cm depth because of the small amount of root material available.

In 1998 all plots were sampled for below-ground biomass in the 0-18 cm depth, but only one plot per block was randomly sampled in the 18-36 cm depth. In 1999 and 2000 only four adjacent plots per block (representing the four legumes) were sampled at the two depths.

After physically removing the roots from the soil in 1999, the remaining soil material from the 24 soil samples, representing the four core positions, was washed through a 0.48 mm sieve to estimate the potential root losses for the "hand method". The results from these determinations are presented in Table 1.4, and the conclusions are included with the below-ground biomass results.

Composite wheat plant samples were collected between the 2-3 tiller and boot stages in 1999, and at the 2-3 tiller stage in 2000, taking 4 sub-samples per plot from a total area of 0.6 m^2. Before mechanical harvest 2 sub-samples per plot were obtained from a total area of 0.3 m^2 in order to determine the straw-grain ratio and their C and N contents. All plant samples were oven-dried at 60° C, weighed, ground (using a 0.5 mm sieve), and analyzed for C and N in a LECO ™ instrument.

The forage and grain/residue yield estimations for legumes were made from the periodic above-ground samples taken before each harvest. For each legume level, the forage yield was derived from all management levels since they were equivalent and their evaluation and harvest/killing were at the same date. Wheat grain yield was estimated using mechanical harvest samples taken with a small combine from one strip per plot (21 m^2). The data were corrected to a 12.5% moisture content.

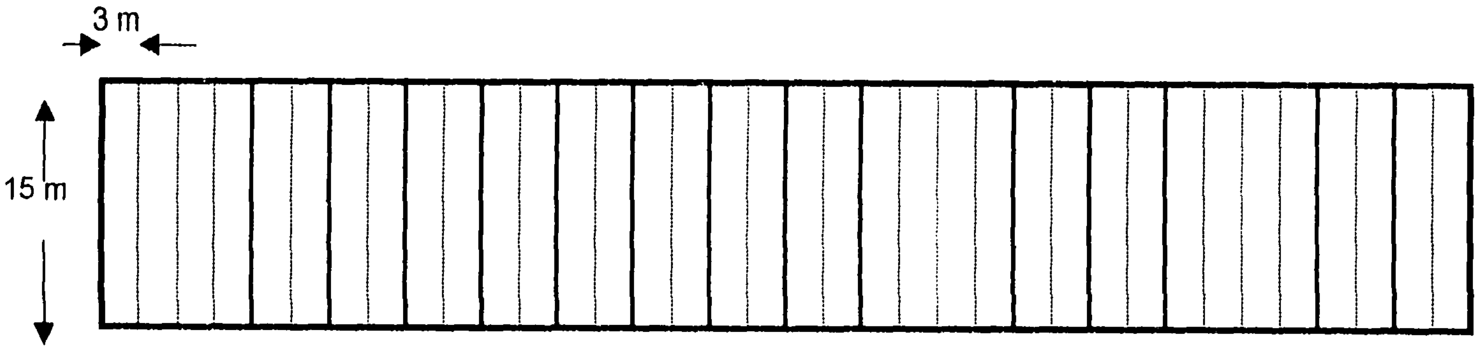
Experimental design

A schematic representation of the complete experiment plan (for a given block) is depicted in Fig.1.2. Each block includes one main plot per factor level: Legume type (4 levels) and Management (3 levels). A control plot using chemical fallow was included and replicated three times in each block. The position of the 15 plots in each block was randomized.

Table 1.4 – Root biomass recovery, and standard deviation (n=2), after washing discarded soil samples through a 0.48 mm sieve in 1999.

	DEPTH							
	0-18 cm				18-36 cm			
	Sampling Position				Sampling Position			
	Row		Side		Row		Side	
CROP	Mean kg ha^{-1}	Std.	Mean kg ha^{-1}	Std.	Mean kg ha^{-1}	Std.	Mean kg ha^{-1}	Std.
Austrian winter pea	17.7	15.0	13.2	4.5	56.6	3.2	60.6	10.4
Profi pea	34.2	9.1	36.5	5.1	85.8	42.7	52.3	45.4
Soybean (1)	10.0	2.9	8.4	2.9	87.0	117.7	27.5	37.0

(1) Asgrow 2301



a) Legume:
1. Austrian Winter Pea
2. Profi Pea
3. Soybean 1
4. Soybean 2
5. Control (with no legume and chemical FALLOW)

b) Management:
F. Forage
G. Grain
M. Green Manure

c) Fertilizer (at wheat planting)
0. No nitrogen fertilizer
40. 40 kg N ha^{-1} nitrogen fertilizer
20. 20 kg N ha^{-1} nitrogen fertilizer (only legume 1)
60. 60 kg N ha^{-1} nitrogen fertilizer (only legume 1)

Fig. 1.2 – Schematic representation of a replication of the whole experiment plan.

Only during winter wheat growth, a third factor (fertilizer) was assigned by splitting each plot in two sub-plots. Two fertilizer levels were used: No nitrogen fertilizer (0N), and forty kg ha^{-1} of nitrogen fertilizer (40N). For Austrian winter pea plots four fertilizer levels were used (0, 20, 40 and 60N). All sub-plots were randomized in each main plot. Four replications (blocks) of this kind were present each year of the study.

Different models were used for the statistical analysis of the data, according to the characteristics and timing of the sampling and determinations:

During legume growth

a) Before the differentiation of the management factor (at forage harvest and killing of the cover crop in green manure level): The statistical model corresponded to a generalized one factor randomized complete block design, repeated three times in each block. The interaction term block x treatment was used as an error term for treatments if considered non-negligible (if negligible, the general error term was used). The general criteria in these cases was a probability value for the F test higher than 0.25.

b) After differentiation of the management factor, the statistical model was a two factor randomized complete block design (legume and management), with a control (fallow) repeated three times in each block. The usual procedure was to run a previous analysis of variance excluding the control in fallow, using a classic two factor randomized complete block design. If the management factor was negligible (a p-value>0.25 was customary considered), the second analysis (using fallow) ignored the management factor into the legume factor becoming a generalized one factor randomized complete block design (with n levels of legume factor plus fallow), repeated three times in each block. When the management factor was not negligible, a one factor randomized complete block design was used (with n legume x m management levels plus fallow).

c) For any determination not including fallow (like legume biomass and yield determinations), the design was a classic factorial (two factors randomized complete block design).

During wheat growth

The main model was a two factor randomized complete block design (legume and management), with a control (fallow) repeated three times in each block, and a third factor (fertilizer) as a split-plot. Like other cases, a previous analysis of variance was run without fallow to assess the importance of the management factor and to allow mean comparisons between legume treatments. A one factor randomized complete block design (legume and management + fallow), with a second factor (fertilizer) as a split-plot was then used, to compare fallow to legumes. In the special case of the Austrian winter pea plots, which had four fertilizer levels during the wheat growing season, a one factor randomized complete block design (Austrian winter pea under three management levels), with a second factor (4 fertilizer levels) as split-plot was used.

Mean comparisons

The standard method used for main effect mean comparisons was the Ryan-Einot-Gabriel-Welsch Multiple Range Test (REGWQ), at α=0.05 probability level. When a significant interaction term made this method inappropriate due to a high number of means other alternative methods were used: Dunnett tests (whenever a comparison against the control was involved); and F-protected Fisher LSD tests.

Chapter 2

RESULTS

1. CLIMATE

Climatic data, monthly precipitation and mean temperature for the study period, are compared to the long-term average in Fig 2.1.

Considering the whole year, 1998 may be characterized as dry because the total annual precipitation (313 mm) was a 74% of the long-term average for the area (422 mm). Despite the high precipitation that occurred in February, the spring months (March, April, May and June) were dry, receiving 28% of the long-term average in this period. The summer months (July, August and September), were slightly above the long-term average (112%) and the fall/winter months had snow precipitation slightly lower than the long-term average (81%), in 1998 the precipitation distribution was not favorable for peas, growing in the beginning of the summer, and favored the vegetative growth of the soybean.

The 663 mm of precipitation in 1999 represented 157% of the long term average. The rainfall was mainly concentrated in the spring and summer months, almost double their average amount (197 and 175% respectively). The fall/winter precipitation was again low; about half of the long-term average (48%). This precipitation distribution was favorable for both the pea and soybean during the summer, but less favorable than the previous year for soil water recharge before wheat planting.

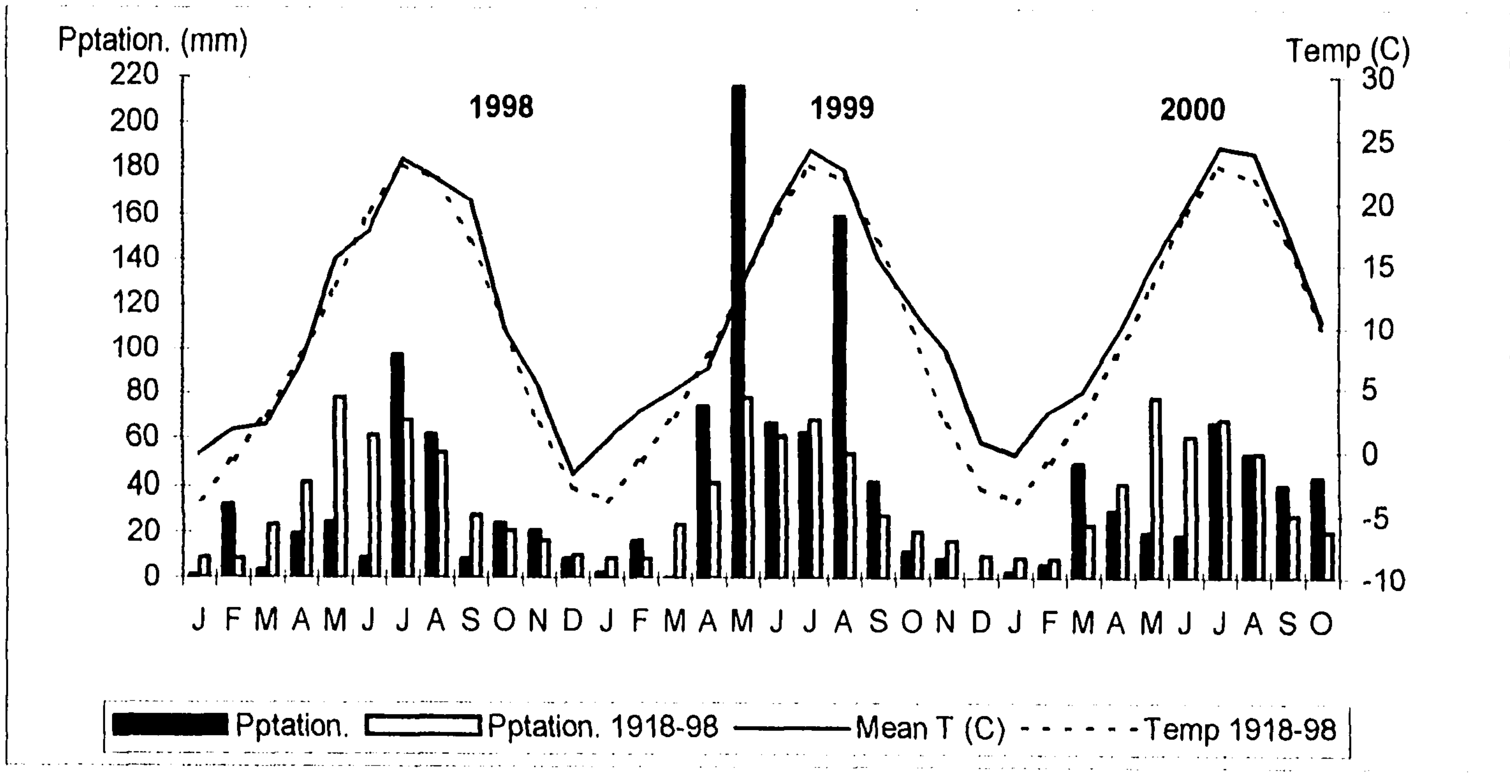


Fig. 2.1 – Monthly precipitation and mean temperature during the period of study, compared to the 1918-1998 long term average.

During 2000, the total rainfall for the January-October period (335 mm), was 85% of the long-term average. The spring months (March, April, May and June), were dry with 58% of the normal precipitation. The summer months (July, August and September), were about average (108%). The rainfall distribution during 2000 was again unfavo rable for pea and average for the soybean production.

Total precipitation for critical periods related to the treatments studied are presented in Table 2.1. The mean temperature during the fall/winter period is of interest since it could affect winter wheat growth and the over-wintering of the Austrian winter pea planted during the fall of 1998 and 1999. For both seasons the temperature was above average (Fig.2.1), favoring the Austrian winter pea, which did not suffered wi nter kill. In 1998/99, the temperature of the November/March period averaged 2.9 ° C higher than the long-term average, while in 1999/2000 the average temperature for the same period was 3.8 °C higher than average.

2. ABOVE-GROUND LEGUME GROWTH

The growing period for the pea and soybean are definitely different in this study (Fig.2.2). While the pea was generally terminated by mid July, the soybean just started its growth by this date and was terminated by the end of September (the Asgrow 3901 variety, the longest maturity group studied in 2000, was in fact harvested in mid October).

1998

In 1998 the plant population and growth of the pea was poor because of the intense drought during spring, which delayed the emergence of the crop and produced an irregular stand. This uneven population allowed weed infestations late in the season, which were favored by rainfall events in July. Kochia (*Kochia scopparia*), and Russian thistle (*Salsola kali*), were the most important weeds present.

Table 2.1 - Precipitation during selected critical periods of the study during 1998, 1999 and 2000.

PERIOD		1998			1999			2000		
From	To	Initial Date	Final Date	Rainfall (mm)	Initial Date	Final Date	Rainfall (mm)	Initial Date	Final Date	Rainfall (mm)
Austrian winter pea planting	Forage harvest	04/30/98	07/17/98	79	10/13/98	06/14/99	397	10/14/99	06/19/00	137
	Grain harvest		07/29/98	110		07/16/99	425		07/13/00	144
	Wheat planting		10/13/98	211		10/14/99	697		10/17/00	304
Profi pea planting	Forage harvest	04/30/98	07/17/98	79	03/26/99	06/14/99	331	03/29/00	06/14/00	64
	Grain harvest		07/29/98	110		07/27/99	402		07/13/00	91
	Wheat planting		10/13/98	211		10/14/99	631		10/17/00	246
Soybeans planting	Forage harvest	05/26/98	08/12/98	170	05/19/99	07/27/99	284	05/30/00	08/15/00	99
	Grain harvest		09/20/98	172		09/23/99	473		09/30/00	182
	Wheat planting		10/13/98	190		10/14/99	512		10/17/00	183
Wheat planting	Wheat harvest	10/13/98	07/07/99	424	10/14/99	07/05/00	144	10/17/00	---	---

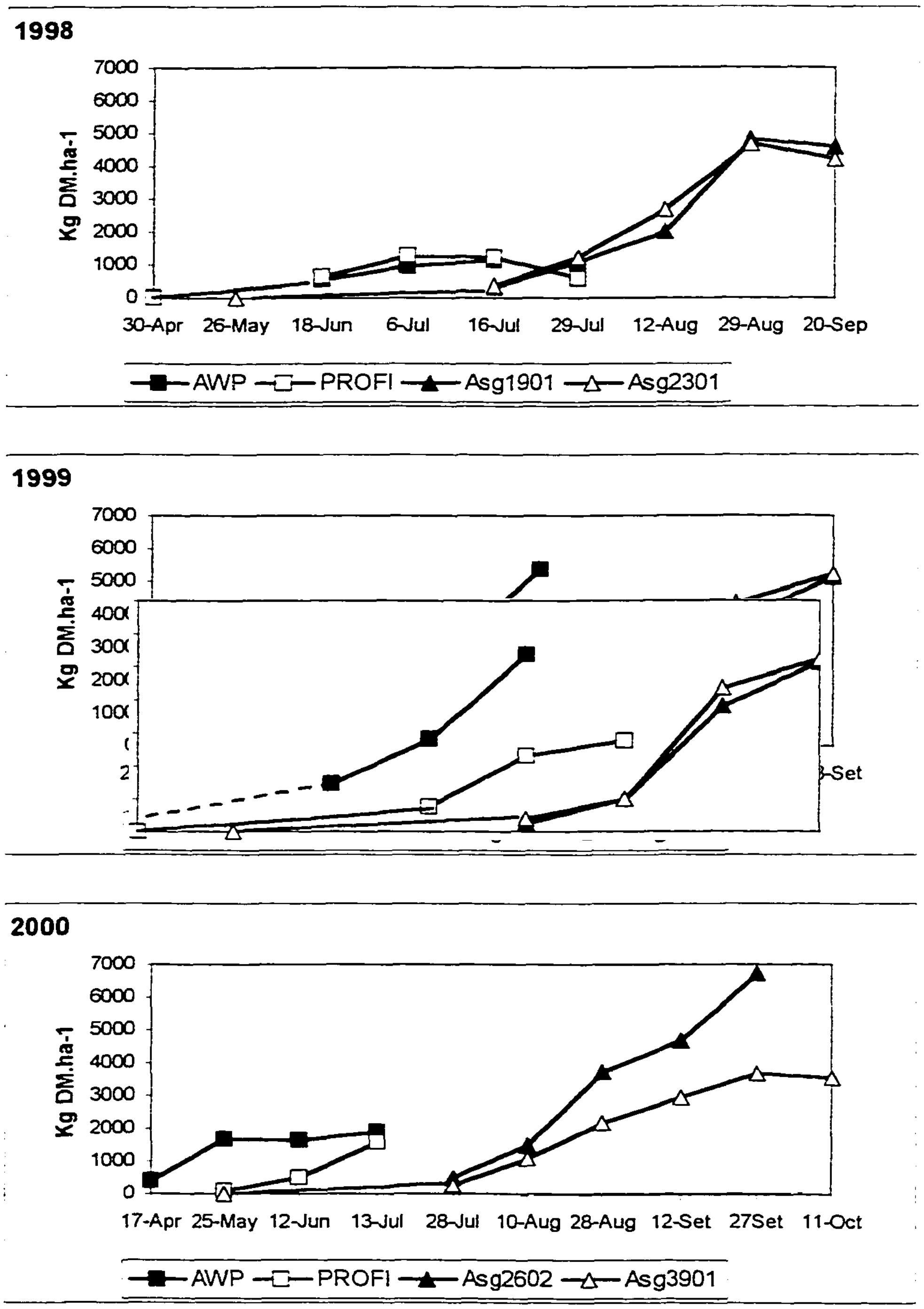


Fig. 2.2 - Legume above-ground dry matter production vs time during 1998, 1999 and 2000.

The soybean had a plant stand slightly lower than expected due to the dry conditions during emergence. However, their growth was less affected by weeds because of the higher rainfall, and the use of Round-up ready varieties that allowed easy weed control. These factors resulted in a better performance of soybean compared to the two pea varieties. The maximum dry matter accumulation in 1998 (including grain in the later stages) was: 1123, 1251, 4824 and 4701 kg ha^{-1} for Austrian winter pea, Profi pea, Asgrow 1901, and Asgrow 2301, respectively (Table 2.2.).

The N concentration in the above-ground legume dry matter (excluding grain) was relatively high early in the growing season and decreased as vegetative and reproductive stages developed. It ranged from 47 to 33 g kg^{-1} in Austrian winter pea, from 34 to 22 g kg^{-1} in Profi pea, and from 45 to 14 g kg^{-1} in the soybean. This decreasing pattern is related to the increase in biomass and consequent nutrient dilution in the plant, and later to re-mobilization of N to the grain.

Given the differences in N content of the above-ground dry matter, the total N uptake during legume growth was driven mainly by dry matter production. The maximum values were 41 and 36 kg N ha^{-1} for Austrian winter pea and Profi pea respectively, and averaged 113 kg N ha^{-1} for the soybean in the last date.

The C:N ratio of the above-ground biomass increased as the growing season progressed, ranging from an average of 11.5 and 9 in the initial stages, to 19 and 31 in plant residues at harvest for the pea and soybean, respectively.

The mechanical forage harvest was on July 17th for the pea, at about 80 days after planting (DAP), and just at the end of the drought. The grain pea treatments ended their reproductive stage at 90 DAP and the serious weed infestations decreased yields. Soybean mechanical forage harvest was on August 12th (78 DAP), and soybean grain harvest on September 20th (117 DAP).

Table 2.2 - Mean above-ground dry matter production, N content, C:N ratio, and N uptake for legumes during 1998.

CROP	PARAMETER	DATE						
		June 18th	July 6th	July 16th	July 29th (a)	Aug 12th	Aug 29th	Sep 20th (b)
Austrian winter pea	D.M. (kg ha^{-1})	553	967	1123	---	---	---	---
	N conc (g kg^{-1})	47.0	39.1	37.5	33.5	---	---	---
	C:N	9.6	10.7	11.1	15.6	---	---	---
	N uptake (kg ha^{-1})	26	37	41	---	---	---	---
Profi pea	D.M. (kg ha^{-1})	634	1251	1228	602	---	---	---
	N conc (g kg^{-1})	34.2	27.4	27.0	31.9	---	---	---
	C:N	13.4	15.4	15.8	13.5	---	---	---
	N uptake (kg ha^{-1})	22	36	32	16	---	---	---
Soybean Asgrow 1901	D.M. (kg ha^{-1})	---	---	303	1072	2016	4824	4583
	N conc (g kg^{-1})	---	---	44.3	40.5	33.3	28.0	37.0
	C:N	---	---	9.3	9.6	12.3	15.5	21.7
	N uptake (kg ha^{-1})	---	---	13	43	66	136	117
Soybean Asgrow 2301	D.M. (kg ha^{-1})	---	---	351	1226	2704	4701	4241
	N conc (g kg^{-1})	---	---	45.7	38.8	32.3	26.9	40.6
	C:N	---	---	8.8	10.0	12.6	16.1	17.6
	N uptake (kg ha^{-1})	---	---	16	47	86	124.8	109

(a) Data for the pea includes the whole plant (grain + residue).
(b) Data for soybean includes the whole plant (grain + residue).

The application of herbicide to stop growth in the Green Manure treatments, both for pea and soybean plots was not effective and thus was repeated. In the case of the pea, a stressed condition of the plants at the time of spraying was the cause of the failure. In soybean, a low proportion of 2,4- D in the product used did not kill the Round-up Ready plants immediately. An application of 2,4- D worked better. In both cases, the delay in the killing of the Green Manure cover allowed additional water use in the Forage treatments.

1999

In 1999 the weed problem, favored by the abundant rainfall, persisted in Profi pea despite the earlier spring planting date, but was avoided in Austrian winter pea. The fall planting of the Austrian winter pea, combined with higher than normal temperatures during winter and favorable precipitation during April and May, produced an excellent dry matter yield and this competition reduced weed growth.

The total dry matter production was: 5354, 2759, 5133, and 5247 kg ha^{-1} for Austrian winter pea, Profi pea, Asgrow 2001 soybean, and Asgrow 2301 soybean, respectively (Table 2.3). The N content of the above-ground biomass (excluding grain), ranged from 40 to 23 g kg^{-1} in Austrian winter pea, 37 to 17 g kg^{-1} in Profi pea, and from 38 to 10 g kg^{-1} in the soybean. The maximum total N uptake in the above-ground biomass was 142, 71, and averaged 170 kg Nha^{-1} for Austrian winter pea, Profi pea, and the soybean, respectively.

The C:N ratio averaged 10 for all legumes at about 50 DAP (including the fall planted Austrian winter pea). At the corresponding grain harvests the ratio for the residue was 18, 25, 39 and 45 for Austrian winter pea, Profi pea, Asgrow 2001 soybean and Asgrow 2301 soybean, respectively.

Table 2.3 - Mean above-ground dry matter production, N content, C:N ratio, and N uptake, for legumes during 1999.

CROP	PARAMETER	DATE					
		May 25th	June14th	July 16th (a)	July 27th	Aug 24th	Set 23rd (b)
Austrian winter pea	D.M. (kg ha^{-1})	1451	2838	5354	---	---	---
	N conc (g kg^{-1})	40.2	32.0	35.5	---	---	---
	C:N	10.8	13.3	13.5	---	---	---
	N uptake (kg ha^{-1})	58	91	142	---	---	---
Profi pea	D.M. (kg ha^{-1})	---	761	2312	2759	---	---
	N conc (g kg^{-1})	---	37.0	29.8	28.7	---	---
	C:N	---	11.7	15.4	17.7	---	---
	N uptake (kg ha^{-1})	---	28	67	71	---	---
Asgrow 2001 soybean	D.M. (kg ha^{-1})	---	---	270	1001	3809	5133
	N conc (g kg^{-1})	---	---	40.5	37.0	34.0	36.3
	C:N	---	---	9.6	10.5	12.6	24.1
	N uptake (kg ha^{-1})	---	---	11	37	130	166
Asgrow 2301 soybean	D.M. (kg ha^{-1})	---	---	400	980	4376	5247
	N conc (g kg^{-1})	---	---	36.3	32.8	32.5	35.1
	C:N	---	---	9.5	11.9	13.2	26.5
	N uptake (kg ha^{-1})	---	---	15	32	143	173

(c) Data for pea includes the whole plant (grain + residue).
(d) Data for soybean includes the whole plant (grain + residue).

The mechanical forage harvest was on June 14th for the peas (244 and 80 DAP for Austrian winter pea and Profi pea, respectively), and July 27th for the soybean (69 DAP). The grain harvest was on July 16th for Austrian winter pea (276 DAP), July 27th for Profi pea (123 DAP), and September 23rd for the soybean (127 DAP).

Due to the poor competitive ability of the Profi pea, the weed infestation in the plots was relatively high. This affected their control in the Green Manure and Grain management treatments because the plants were older and more resistant at the time of herbicide application. The weeds in the Forage management, having been cut mechanically, were easily controlled. In the soybean, the suppression of plants at termination time for Green Manure management was also slow, due in this case to the frequent rainfall that interfered with the herbicide application and effect.

2000

The Austrian winter pea had irregular emergence because of low precipitation during the fall, and went through the winter with a relatively reduced population. This encouraged the proliferation of volunteer wheat from the previous crop. The average plant composition in the plots was 60% Austrian winter pea and 40% volunteer wheat. Profi pea, planted at the end of March, had a difficult emergence due to the presence of a surface crust that interfered with the planter operation. This again caused a thin plant stand and the proliferation of weeds resulting in poor dry matter production.

Soybean was planted during a prolonged drought. Despite the fact that the soil had enough water content for plant establishment and growth, the presence of a dry surface crust with variable thickness prevented the planter from placing the seed in moist soil. Thus a poor plant stand resulted with numerous blank spots that increased yield variability.

The total dry matter production was 1931, 1591, 4666 and 2966 kg ha^{-1} for Austrian winter pea, Profi pea, Asgrow 2602 soybean and Asgrow 3901 soybean respectively (Table 2.4). The N content in the above-ground biomass ranged from 27 to 39 g $kg^{-1}$for Austrian winter pea, from 48 to 25 g kg^{-1} in Profi pea, and from 38 to 35 g kg^{-1} in the soybean.

The maximum N uptake was 67 and 30 kg N ha^{-1} for Austrian winter pea and Profi pea, respectively, and 151 and 80 kg N ha^{-1} for Asgrow 2602 soybean and Asgrow 3901 soybean respectively.

The C:N ratio was 16 for Austrian winter pea, and averaged 10 for the rest of the legumes in the first determination, and 16, 32, 50, and 36 in the residues after harvest for Austrian winter pea, Profi pea and soybean, respectively.

The mechanical forage harvest was on June 19th for the peas (249 DAP for Austrian winter pea and 82 DAP for Profi pea), and on August 15th for the soybeans (76 DAP). Soybean harvest was on September 27th for Asgrow 2602, and October 11th for Asgrow 3901 (119 and 133 DAP respectively). In 2000 harvest dates were different due to differences in maturity group.

The suppression of plants in all pea management after their intended termination data was difficult. The plants were stressed by the drought at the first herbicide application and later rainfall favored the re-growth of new weeds. In the soybean, however, the termination of the Green Manure treatment was complete and timing was good for the Forage treatment due to an earlier herbicide application.

3. LEGUME FORAGE AND GRAIN YIELD

The forage, grain yields and corresponding N content for both legume groups during the period under study are presented in Fig 2.3 and Table 2.5. The climate in the three years of study varied substantially and made it difficult to do a general analysis based on averages. In 1998 the soybeans produced more forage than the peas; in 1999 Austrian winter pea had the highest yield, with no differences among the other three

Table 2.4 - Mean above-ground dry matter production, N content, C:N ratio, and N uptake for legumes during 2000.

CROP	PARAMETER	DATE April 17th	May 25th	June 12th	July 13th	July 28th	Aug 10th	Aug 28th	Set 12th	Set 27th	Oct 11th
Austrian winter pea	D.M.(kg ha^{-1})	393	1692	1658	1930	---	---	---	---	---	---
	N conc (g.kg^{-1})	27.0	39.0	35.0	38.25	---	---	---	---	---	---
	C:N	15.6	11.0	12.1	12.5	---	---	---	---	---	---
	N uptake(kg ha^{-1})	11	67	57	58	---	---	---	---	---	---
Profi pea	D.M.(kg ha^{-1})	---	93	505	1591	---	---	---	---	---	---
	N conc (g.kg^{-1})	---	48.0	32.0	25.3	---	---	---	---	---	---
	C:N	---	9.0	13.6	22.1	---	---	---	---	---	---
	N uptake(kg ha^{-1})	---	5	16	30	---	---	---	---	---	---
Asgrow 2602 soybean	D.M.(kg ha^{-1})	---	---	---	---	512	1480	3740	4666	6746	---
	N conc (g.kg^{-1})	---	---	---	---	39.0	34.9	29.9	25.5	34.8	---
	C:N	---	---	---	---	10.4	11.6	13.7	16.9	29.5	---
	N uptake(kg ha^{-1})	---	---	---	---	19	51	112	120	151	---
Asgrow 3901 soybean	D.M.(kg ha^{-1})	---	---	---	---	286	1111	2193	2966	---	3556
	N conc (g.kg^{-1})	---	---	---	---	38.0	31.8	30.6	27.1	---	37.3
	C:N	---	---	---	---	10.6	11.8	13.1	15.3	---	22.3
	N uptake(kg ha^{-1})	---	---	---	---	11	35	67	80	---	80

Data for the last dates includes the whole plant (grain + residue).
DM= Dry matter, Nconc= N content, C:N= carbon:nitrogen ratio, Nuptake= nitrogen uptake.

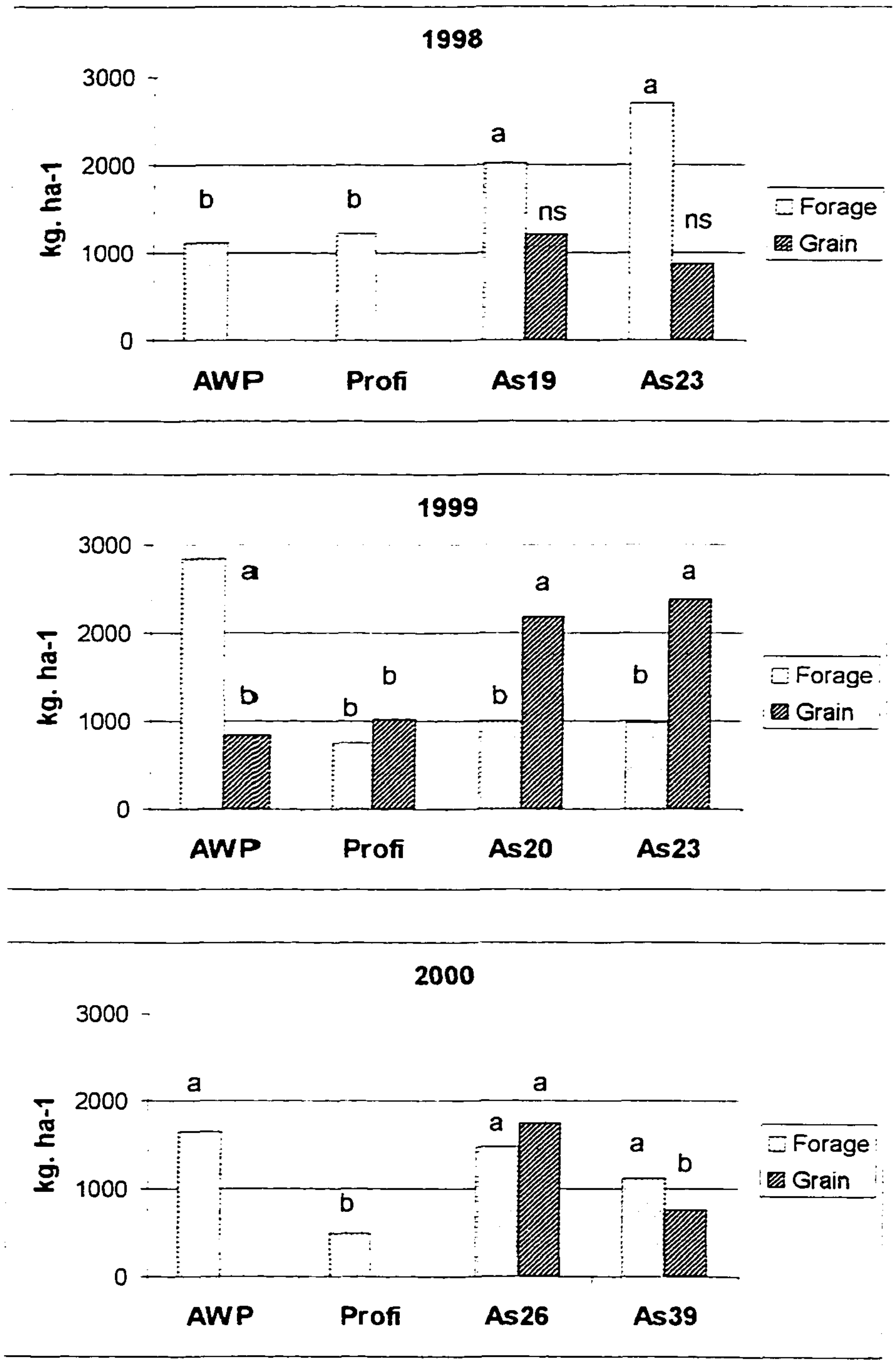


Fig.2.3 – Legume forage and grain production during the period studied. For each variable yields with the same letter are not different (α=0.05)

Table 2.5 – Legume forage, grain and residue production, N content, and N uptake in 1998, 1999 and 2000.

		YEAR								
		1998 Management			1999 Management			2000 Management		
Crop	Parameter	Forage	Grain: Grain	Grain: Res.	Forage	Grain: Grain	Grain: Res.	Forage	Grain: Grain	Grain: Res.
Austrian Winter Pea	D.M. (kg ha^{-1})	1123 b	---	---	2838 a	832 b	4522 a	1658 a	---	---
	N conc (g kg^{-1})	37.5 a	46.6 b	19.5 a	32.2 b	48.3 b	22.6 a	34.5 ns	50.2 b	26.3 a
	C:N	11.1 c	9.3 b	21.8 bc	13.3 a	8.7 b	18.1 c	12.1 ab	8.9 b	16.1 c
	N uptake (kg ha^{-1})	41 b	---	---	91 a	40 b	102 a	57 a	---	---
Profi Pea	D.M. (kg ha^{-1})	1228 b	---	---	761 b	1014 b	1745 c	505 b	---	---
	N conc (g kg^{-1})	27.0 c	42.0 c	21.8 a	36.9 a	40.2 c	17.3 b	31.8 ns	37.5 c	13.1 b
	C:N	15.8 a	10.1 a	16.8 c	11.7 b	10.4 a	25.0 b	13.6 a	11.8 a	32.3 b
	N uptake (kg ha^{-1})	32 b	---	---	28 b	41 b	30 b	16 b	---	---
Soybn 1 (a)	D.M. (kg ha^{-1})	2016 a	1206 ns	3377ns	1001 b	2179 a	2954 b	1480 a	1741 a	5005 a
	N conc (g kg^{-1})	33.3 b	61.4 a	12.5 b	37.0 a	61.7 a	10.7 c	34.9 ns	60.2 a	9.4 c
	C:N	12.3 b	8.3 c	35.2 a	10.5 c	8.1 c	39.2 a	11.6 b	8.6 bc	50.3 a
	N uptake (kg ha^{-1})	66 a	74 ns	42 b	37 b	134 a	32 b	51 a	105 a	46 a
Soybn 2 (b)	D.M. (kg ha^{-1})	2704 a	867 ns	3374 ns	980 b	2385 a	2862 b	1111 a	746 b	2810 b
	N conc (g kg^{-1})	32.3 b	64.9 a	16.2 ab	32.8 b	61.0 a	9.5 c	31.8 ns	62.6 a	11.9 bc
	C:N	12.6 b	7.7 d	27.4 ab	11.9 b	8.3 c	44.7 a	11.8 ab	8.23 c	36.4 ab
	N uptake (kg ha^{-1})	86 a	56 ns	53 a	32 b	146 a	27 b	35 a	47 b	33 a

(a) Asgrow 1901, 2001 and 2602 in 1998, 1999 and 2000 respectively.
(b) Asgrow 2301, 2301 and 3901 in 1998. 1999 and 2000 respectively.
DM = Dry matter, Nc = N content, C:N = carbon-nitrogen ratio, Nup = nitrogen uptake.
For each column and variable values with the same letter are not different at α=0.05 level.

legumes; in 2000 Austrian winter pea and soybean produced more forage than Profi pea.

The N content of the forage was variable over the three years. In 1998 Austrian winter pea hay had more N than soybean and Profi pea. In 1999, Profi pea and Asgrow 2001 soybean had higher N contents than Austrian winter pea and Asgrow 2301 soybean. In 2000 there were no significant differences in forage N content.

The grain production was essentially zero for both pea types in 1998 and 2000, and was less than the soybean yield in 1999. There were no significant differences between soybean variety grain yields in 1998 and 1999, but in 2000 Asgrow 2602 yielded more than Asgrow 3901.

The soybean had higher grain N content and N uptake than either pea types in all three years. The C:N ratio in soybean residues was also higher (though not always significant) than the pea.

4. BELOW-GROUND LEGUME GROWTH

Fig. 2.4 presents the total root dry matter production for each legume and year; showing the relationships between positions and depths. In all three years, the legumes had more root biomass in the 0-18 cm than in the 18-36 cm depth ($p < 0.0001$ for factor depth). They also had more root biomass in the row than on the side in the 0-18cm depth ($p < 0.0001$ for factor position). In the 18-36 cm layer the data were more variable, and there were interactions of legume x depth and legume x position due to different orders of the legume means related to the 0-18cm layer (Table 2.6).

Nodules were present on all legumes every year, but were not recovered from the pea during the 1998 sampling, even though they were visually present early in the season.

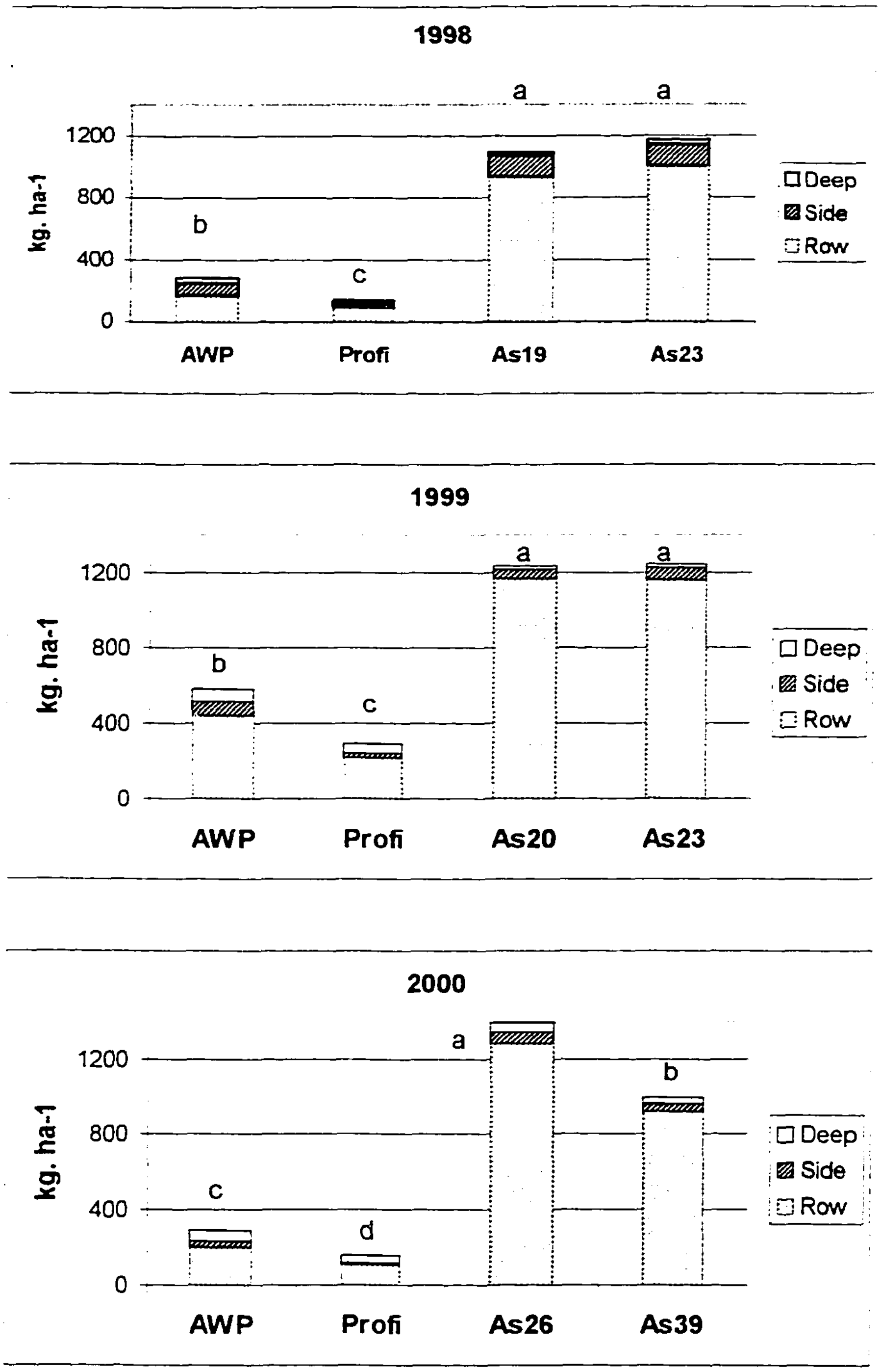


Fig. 2.4 – Legume below-ground dry matter. Row= central core over crop row (0-18cm), Side= lateral core in inter-row (0-18cm), Deep= 18-36cm depth. Bars with the same letter are not different at α=0.05 level.

Table 2.6 – Below-ground legume dry matter and N uptake by depth, in 1998, 1999 and 2000.

		YEAR								
		1998 Depth (cm)			1999 Depth (cm)			2000 Depth (cm)		
Crop	Parameter	0-18	18-36	0-36	0-18	18-36	0-36	0-18	18-36	0-36
Austrian w. pea	Dry matter (kg ha^{-1})	169 b	51 b	220 b	513 b	63 a	576 b	229 b	65 a	294 c
	N uptake (kg ha^{-1})	5.6 b	0.7 a	6.3 b	12.5 a	1.1 ns	13.6 b	6.1 c	1.1 a	7.2 c
Profi pea	Dry matter (kg ha^{-1})	94 c	23 b	117 c	242 c	47 b	289 c	120 c	36 bc	156 d
	N uptake (kg ha^{-1})	2.7 c	0.4 ab	3.1 c	4.3 b	0.7 ns	5.0 b	2.3 d	0.7 ab	3.0 d
Soybean (a)	Dry matter (kg ha^{-1})	938 a	133 a	1071 a	1215 a	21 c	1236 a	1343 a	53 ab	1396 a
	N uptake (kg ha^{-1})	11.6 a	0.3 b	11.9 a	18.0 a	0.4 ns	18.4 a	17.2 a	0.7 ab	17.7 a
Soybean (b)	Dry matter (kg ha^{-1})	1004 a	140 a	1144 a	1220 a	20 c	1240 a	964 a	32 c	995 b
	N uptake (kg ha^{-1})	14.4 a	0.5 b	14.9 a	17.7 a	0.3 ns	18.0 a	12.2 b	0.5 b	12.7 b

(a) Asgrow 1901, 2001 and 2602 in 1998, 1999 and 2000 respectively.
(b) Asgrow 2301, 2301 and 3901 in 1998, 1999 and 2000 respectively.
In each column, variables with the same letter do not differ at α=0.05 level

Differences in below ground dry matter among legumes were similar for both row and side positions. The total below-ground production of the soybeans was greater than that for the other two legumes in the three years studied.

The N content and C:N ratio of the roots were variable and were affected by the morphology of each legume group (Tables 2.7.1 and 2.7.2):

a) The soybean taproots had an average N content of 9.1 g kg^{-1}. The thin roots averaged 12.5 g N kg^{-1} in the surface row position, and their N content increased slightly in the side position and in the18-36 cm depth (thinner roots) with an overall average of 15.9 g kg^{-1}. The average C:N ratio was 50.6, 34.2, and 25.5 for the taproots, row thin roots, and side/deep roots respectively. Nodules contained the highest N concentration (57.9 g N kg^{-1}), and had the lowest C:N ratio (7.2), but less biomass than the other root parts. Nevertheless, their contribution to below-ground N uptake could be considered important in 1999 and 2000.

b) The pea roots were all considered "thin". The Austrian winter pea roots had a N content of 20 g kg^{-1} and a C:N ratio of 19.2, and the Profi pea roots 18.3 g kg-1 and 21.4 respectively. Data for both legumes included the row, side and deep positions. The N content and C:N of the nodules were respectively 40.8 g kg^{-1} and 9.6 for Austrian winter pea, and 34.6 g kg^{-1} and 11.4 for Profi pea.

The total N uptake data presented in Fig. 2.5, and Table 2.6, showed that the 0-18 cm depth always had a higher N uptake than the 18-36 cm depth ($p<0.0001$ for depth factor). The row position had more N uptake than the side in all three years ($p<0.0001$ for position factor). During the three years of study soybean had higher N uptake in roots than both pea types. In 1999 the N uptake of Austrian winter pea was lower, but not significantly different from the soybean in the 0-18 cm depth. Profi pea always had the lowest N uptake, with Austrian winter pea intermediate.

Table 2.7.1 – Mean below-ground legume dry matter, N content, C:N ratio, and N uptake by depth, position and root part. (0-18cm depth)

	YEAR											
	1998 Position				1999 Position				2000 Position			
	ROW			SIDE	ROW			SIDE	ROW			SIDE
	Tap	Thin	Nods.	Thin	Tap	Thin	Nods.	Thin	Tap	Thin	Nods.	Thin
Austrian winter pea												
D.M.	---	169	---	51	---	247	194	73	---	153	48	28
N conc	---	25.7	---	24.3	---	18.3	34.4	15.7	---	21.1	47.2	20.6
C:N	---	15.0	---	16.3	---	20.4	10.7	19.3	---	17.6	8.4	17.7
N uptake	---	4.4	---	1.2	---	4.5	6.8	1.1	---	3.2	2.3	0.6
Profi pea												
D.M.	---	94	---	23	---	168	45	28	---	96	8	16
N conc	---	23.7	---	20.7	---	17.1	26.1	17.2	---	17.3	43.0	18.4
C:N	---	17.3	---	20.2	---	21.7	13.8	18.8	---	22.9	9.0	21.8
N uptake	---	2.2	---	2.7	---	2.9	1.2	0.5	---	1.6	0.3	0.3
Soybean 1 (a)												
D.M.	665	265	8.8	133	814	256	96	49	969	203	116	55
N conc	9.1	11.5	56.0	15.7	10.2	13.0	58.3	14.1	7.0	12.6	58.6	17.9
C:N	49.4	37.3	7.2	25.1	44.5	32.2	7.2	25.2	64.1	33.7	7.3	21.9
N uptake	6.0	3.0	0.5	2.1	8.4	3.3	5.6	0.7	6.8	2.6	6.8	1.0
Soybean 2 (b)												
D.M.	691	283	30	140	906	161	96	59	687	172	62	43
N conc	10.5	11.6	58.9	14.4	10.2	12.6	56.1	14.8	7.6	13.7	59.7	18.0
C:N	42.8	37.7	7.0	25.5	44.1	33.9	7.1	23.5	58.7	30.6	7.2	22.0
N uptake	7.3	3.3	1.8	2.0	9.1	2.1	5.4	0.9	5.2	2.4	3.8	0.8

(a) Soybean 1: Asgrow 1901, 2001 and 2602 in 1998, 1999 and 2000 respectively.
(b) Soybean 2: Asgrow 2301, 2301 and 3901 in 1998, 1999 and 2000 respectively.
D.M.= dry matter (kg ha^{-1}), N conc=N content (g kg^{-1}), C:N= carbon:nitrogen ratio, N uptake = N uptake (kgha^{-1}).

Table 2.7.2 – Average below-ground legume dry matter, N content, C:N ratio, and N uptake by depth, position and root part. (18-36 cm depth)

	YEAR											
	1998 Position				1999 Position				2000 Position			
	ROW			SIDE	ROW			SIDE	ROW			SIDE
	Tap	Thin	Nods.	Thin	Tap	Thin	Nods.	Thin	Tap	Thin	Nods.	Thin
Austrian winter pea												
D.M.	---	16	---	15	---	43	---	21	---	43	---	22
N conc	---	22.0	---	22.0	---	17.5	---	17.5	---	17.5	---	17.0
C:N	---	19.5	---	19.5	---	22.4	---	22.4	---	23.1	---	20.5
N uptake	---	0.3	---	0.3	---	0.7	---	0.4	---	0.8	---	0.4
Profi pea												
D.M.	---	8	---	13	---	32	---	15	---	17	---	20
N conc	---	17.0	---	17.0	---	14.7	---	14.7	---	18.9	---	17.9
C:N	---	25.4	---	25.4	---	21.7	---	21.7	---	22.1	---	22.5
N uptake	---	0.1	---	0.2	---	0.5	---	0.2	---	0.3	---	0.4
Soybean 1 (a)												
D.M.	---	12	---	6	---	14	---	7	---	31	---	21
N conc	---	16.3	---	16.3	---	19.8	---	19.8	---	11.3	---	13.5
C:N	---	26.7	---	26.7	---	18.6	---	186	---	39.2	---	30.1
N uptake	---	0.2	---	0.1	---	0.3	---	0.1	---	0.4	---	0.3
Soybean 2 (b)												
D.M.	---	7	---	19	---	10	---	9	---	17	---	15
N conc	---	1.7	---	19.7	---	16.0	---	16.0	---	15.9	---	15.2
C:N	---	21.6	---	21.6	---	23.6	---	23.6	---	26.8	---	27.8
N uptake	---	0.1	---	0.4	---	0.2	---	0.1	---	0.3	---	0.2

(c) Soybean 1: Asgrow 1901, 2001 and 2602 in 1998, 1999 and 2000 respectively.
(d) Soybean 2: Asgrow 2301, 2301 and 3901 in 1998, 1999 and 2000 respectively.
D.M.= dry matter (kg ha^{-1}), N conc=N content (g kg^{-1}), C:N= carbon:nitrogen ratio, N uptake= N uptake (kg ha^{-1}).

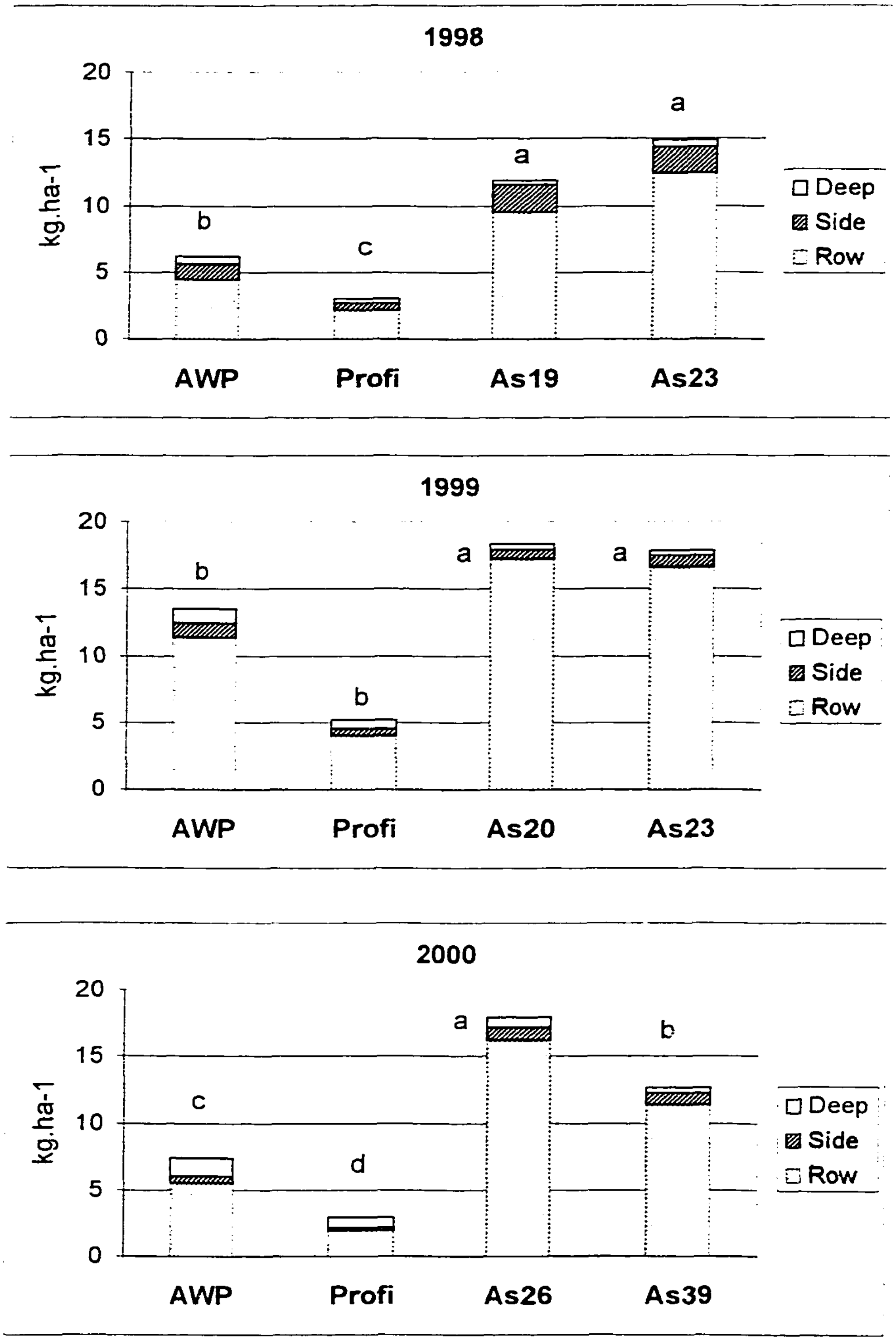


Fig.2.5 – Legume root below-ground N uptake. Row= central core over crop row (0-18cm), Side= lateral cores in the inter-rows (0-18cm), Deep= 18-36cm depth. Bars with the same letter are not different at α=0.05 level.

5. SOIL WATER CONTENT

Fallow

The change in total soil water content was small, indicationg no water storage occurred during the spring-summer portion of the fallow during the three seasons studied (Fig.2.6). In 1998 the fitted linear equation had no significant slope (p=0.91). The fallow period started with an average value of 279 mm of water, and ended with 266 mm. Total rainfall during this period was 211 mm, and the water storage efficiency of the fallow was negative (-0.8%); meaning that all precipitation was lost plus some soil water, due to evaporation.

In 1999, fallow water content at the beginning was 263 mm and it ended with 337 mm. That represents a positive balance of 74 mm of water stored through a period with high precipitation. Rainfall during the fallow was 607 mm, and the efficiency was positive, but low, since only 12% of the rainfall remained in the soil. Solving the fitted quadratic equation for its maximum value, showed that it occurred at the end of August (day 242), with 338 mm. This divides the fallow in two parts: the first one (April to August) with a positive soil water balance (+72 mm), related to extremely favorable conditions. The second part (September and October), had decreasing rainfall and temperatures above the long-term means. This combined with a high soil water content and a low soil cover explains the lack of water storage in the second part of the fallow.

In 2000, the initial soil water content was 333 mm, and after 230 mm of precipitation during the fallow, the soil had 311 mm of total water, representing a storage efficiency –9.6%. Again, all precipitation during fallow plus some amount of soil water were lost.

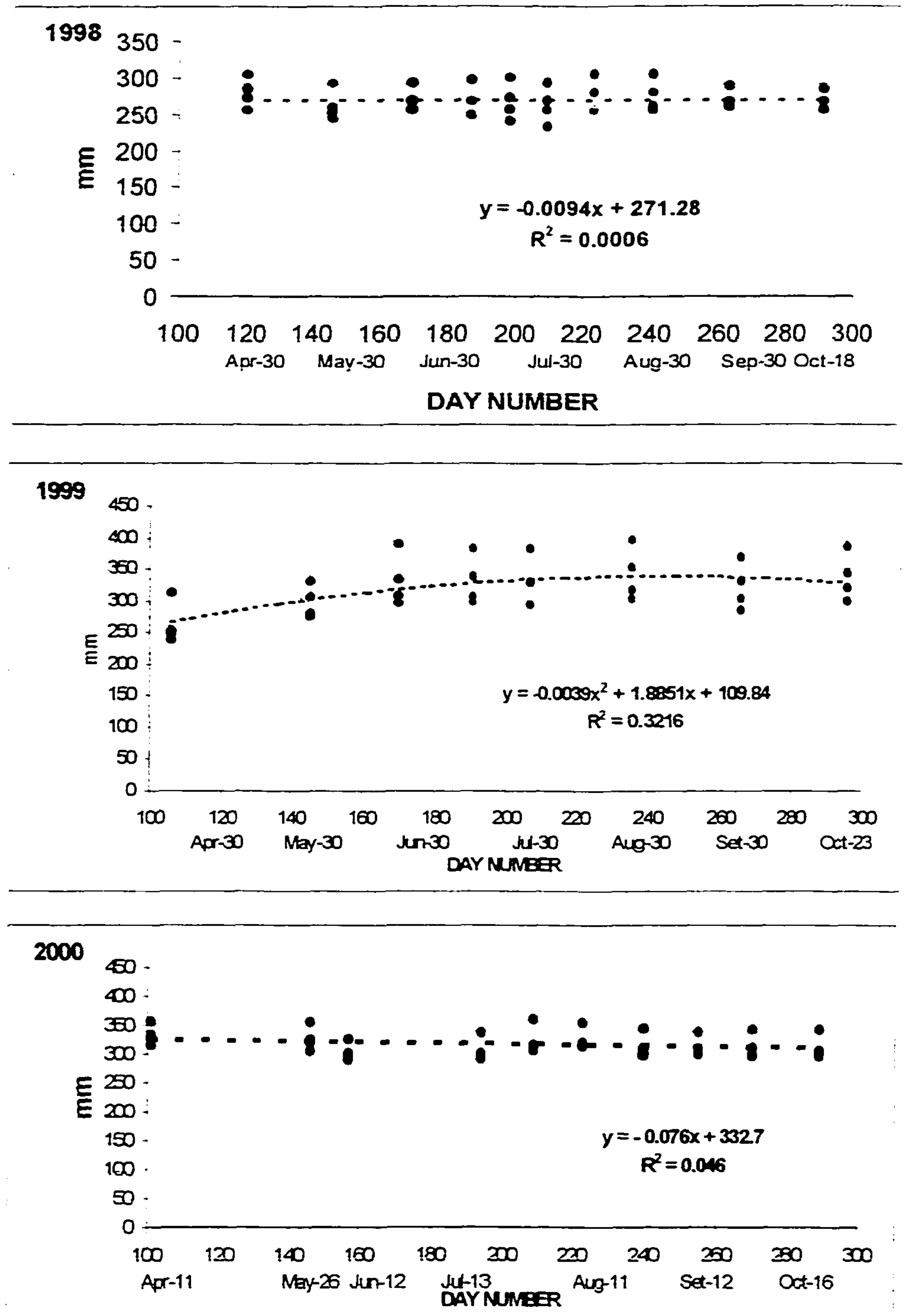


Fig. 2.6 - Total soil water content variation (0-120cm) during fallow in 1998, 1999 and 2000. Day number begins with January 1st.

Legumes

Tables 2.8, 2.9 and 2.10 show the total soil water content in the four soil depths of all treatments at some important dates during the summer growing season: a) Initial time of measurement (usually at pea planting), b) pea forage harvest, c) soybean forage harvest, and d) wheat planting.

Since the available water estimations are based on assumptions (see Materials and Methods chapter), only the total water content in mm/30cm are presented in these tables. As a reference point the estimated water content at wilting point and field capacity are shown for each layer, at the bottom of each table.

1998

a) The soil water content at the beginning of the study period was near to field capacity in the upper layers (0-60cm), but the deeper layers (60-90cm) were near the wilting point.

b) At pea forage harvest (middle July) Austrian winter pea had the lowest soil water content compared to Fallow and soybean, with Profi pea being intermediate. The differences in the profile occurred only in the 0-60cm depth, with the soil under pea having less water than under all other treatments. (Table 2.8)

c) At soybean forage harvest no data were recorded for the pea plots. The soil in the soybean plots had a water content similar to Fallow in the total profile, but had less water in the 0-30 cm layer. (Table 2.8)

e) At wheat planting, the total soil water content in 0-120 cm ranged from 198 mm under the Austrian winter pea and Asgrow 2301 for Grain, to 266 mm under the Profi pea for Green Manure (Fig.2.7 and Table 2.8). Considering the 148 mm of estimated water content at wilting point for this soil, the plant available water for the wheat ranged from 50 to 118 mm.

Table 2.8 – Total soil water content at different dates during the legume growing season in 1998.

Crop		0-30	30-60	60-90	90-120	Total
		DEPTH (cm)				
		mm of water				
		Legume planting (April 30th, 1998)				
All plots		88.3	82.2	60.0	48.8	279.3
		Pea Forage Harvest (July 17th, 1998)				
Fallow		85 a	78 a	54 ns	52 ns	268 ab
Asgrow 1901		84 a	77 a	55 ns	52 ns	267 ab
Asgrow 2301		84 a	78 a	59 ns	54 ns	273 a
Profi pea		71 b	65 b	54 ns	52 ns	242 bc
Austrian w.pea		64 b	58 b	53 ns	50 ns	225 c
F test		12.16	10.13	1.06	0.71	7.53
p-value		0.000	0.000	0.387	0.591	0.000
		Soybean Forage Harvest (Aug. 12th,1998)				
Fallow		93 a	78 ns	54 ns	49 ns	274 ns
Asgrow 1901		82 b	70 ns	51 ns	50 ns	253 ns
Asgrow 2301		79 b	69 ns	55 ns	52 ns	255 ns
Profi pea		---	---	---	---	---
Austrian w.pea		---	---	---	---	---
F test		8.28	2.75	0.93	0.90	3.15
p-value		0.001	0.080	0.404	0.418	0.058
		Wheat Planting (Oct. 13th, 1998)				
Fallow		79 a	79 a	57 a	51 a	266 a
Asgrow	F	71 ab	69 ab	50 ab	47 ab	238 abc
1901	G	56 abc	60 ab	46 ab	43 b	205 c
	M	66 abc	59 ab	48 ab	50 ab	223 abc
Asgrow	F	62 abc	65 ab	54 ab	53 ab	235 abc
2301	G	51 bc	59 ab	43 b	45 ab	198 c
	M	56 bc	60 ab	46 ab	46 ab	209 bc
	F	63 abc	63 ab	45 b	45 ab	216 abc
Profi pea	G	64 abc	65 ab	49 ab	46 ab	224 bc
	M	73 a	76 ab	62 ab	55 ab	266 ab
Austrian	F	60 abc	54 b	49ab	49 ab	211 bc
Winter	G	48 c	58 b	48 ab	43 b	198 c
Pea	M	56 bc	60 ab	47 ab	45 ab	209 bc
F test		5.18	2.41	2.49	2.57	10.70
p-value		0.000	0.020	0.014	0.011	0.001
Estimated W.P.		35	39	39	35	148
Estimated F.C.		98	109	109	98	414

F= Forage, G= Grain, and M= Green Manure management levels.
In each column numbers with the same letter are not different (α=0.05).

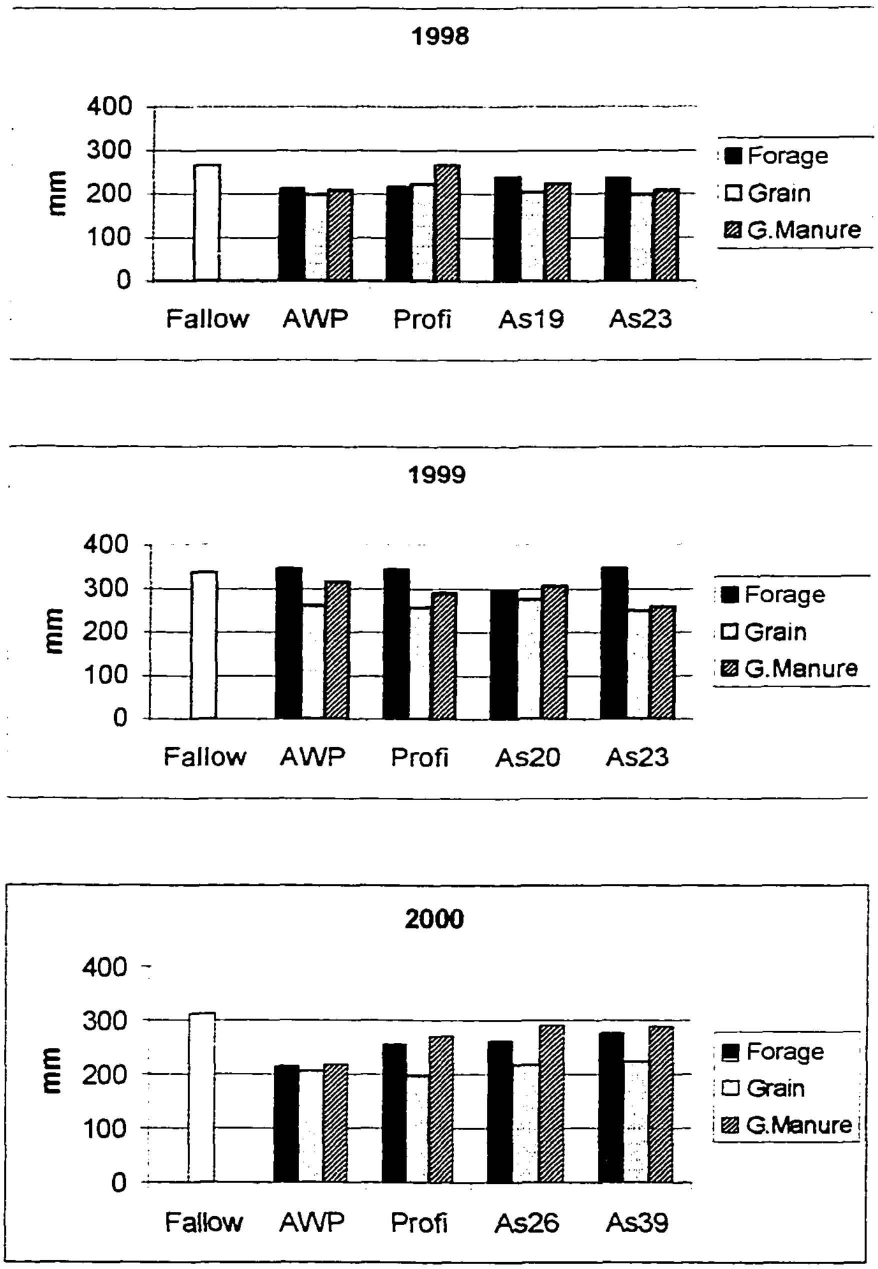


Fig.2.7 – Total soil water content (0-120cm) at wheat planting for each year of the study.

The Fallow control had more soil water in the 0-120 cm depth than all legumes managed for Grain, except Profi pea. Austrian winter pea for Grain had consistently less water than Fallow in all depths, while Profi pea had no significant differences in any soil layer. The other Grain management treatments had lower water content than fallow in at least one layer. (Table 2.8)

Soybean for Forage was not significantly different from Fallow in the whole profile or in any layer. The peas had significant differences in at least one soil layer, with Austrian winter pea having the least soil water. (Table 2.8)

In the Green Manure management, Austrian winter pea and Asgrow 2301 had less water than Fallow, mainly due to differences in the surface layer. (Table 2.8)

1999

a) Since Austrian winter pea was planted during the previous fall (1998), by spring planting some soil water had been used by the Austrian pea (26 mm), especially in the deeper layers (60-90cm). Like the previous year, the soil profile had more water in the 0-60cm depth than in 60-90cm, where it was close to the wilting point value. (Table 2.9)

b) At pea forage harvest all Fallow and legume plots had more soil water than Austrian winter pea. The differences were present in the whole profile (0-120 cm), but were less pronounced in the 90-120 cm. (Table 2.9)

c) At soybean forage harvest all pea treatments had less soil water than Fallow, but the difference was not significant (α=0.05) for the Forage management treatment. The water content in the soybean plots was not different from Fallow. Relative to soybean, the soil water content under peas was less mainly in the Grain management treatments. (Table 2.9).

Only Profi pea for Grain had less soil water than Fallow in the 0-30 cm depth, the other treatments were not different at α=0.05 level. In the 30-60 cm depth the differences

Table 2.9 – Total soil water content at different dates during the legume growing season in 1999.

Crop		DEPTH (cm) 0-30	30-60	60-90	90-120	Total
		mm of water				
		Legume Planting (May 26th, 1999)				
Austrian w. pea		74	67	41	37	220
All other plots		78	71	54	42	245
		Pea Forage Harvest (June 14th, 1999)				
Fallow		103 a	94 a	76 a	59 a	332 a
Asgrow 2001		99 a	96 a	67 a	51 ab	313 a
Asgrow 2301		104 a	99 a	80 a	59 a	342 a
Profi pea		94 a	90 a	64 a	48 ab	295 a
Austrian w. pea		73 b	64 b	44 b	40 b	220 b
F test		14.13	21.20	12.07	4.91	18.24
p-value		0.000	0.000	0.000	0.002	0.000
		Soybean Forage Harvest (July 27th, 1999)				
Fallow		96 ab	91 a	75 a	65 a	326 a
Asgrow	F	83 abc	77 abc	63 abc	57 abc	280 abc
2001	G	87 abc	90 a	68 abc	56 abc	300 ab
	M	88 abc	96 a	67 abc	57 abc	308 ab
Asgrow	F	85 abc	93 a	82 a	61 ab	321 a
2301	G	86 abc	88 a	73 ab	57 abc	304 ab
	M	81 abc	78 ab	67 abc	60 abc	286 abc
	F	86 abc	89 a	66 abc	58 abc	299 ab
Profi pea	G	66 c	57 cd	45 cd	39 bc	205 d
	M	73 bc	60 bcd	55 abcd	44 bc	232 bcd
Austrian	F	100 a	73 abc	49 bcd	44 bc	266 abcd
Winter	G	78 abc	51 d	37 d	37 c	203 d
Pea	M	78 abc	57 bcd	46 cd	42 bc	222 cd
F test		3.37	10.06	5.88	4.41	7.97
p-value		0.002	0.000	0.000	0.000	0.000
		Wheat Planting (Oct. 14th, 1999)				
Fallow		101 ns	91 ab	77 a	68 a	337 a
Asgrow	F	95 ns	78 abc	64 ab	59 ab	295 ab
2001	G	84 ns	76 abc	61 ab	55 ab	276 ab
	M	97 ns	89 abc	63 ab	57 ab	306 ab
Asgrow	F	102 ns	101 ab	82 ab	62 ab	348 ab
2301	G	86 ns	65 bc	51 ab	48 ab	249 b
	M	84 ns	66 c	55 ab	54 ab	259 ab
	F	103 ns	102 a	73 ab	67 ab	344 ab
Profi pea	G	90 ns	72 abc	52 b	43 b	257 b
	M	93 ns	82 abc	65 ab	52 ab	291 ab
Austrian	F	107 ns	97 abc	79 ab	65ab	346 ab
Winter	G	89 ns	75 abc	53 ab	45 b	262 ab
Pea	M	99 ns	87 abc	69 ab	60 ab	315 ab
F test		1.81	2.92	2.32	2.20	2.81
p-value		0.076	0.005	0.023	0.029	0.006
Estimated W.P.		35	39	39	35	148
Estimated F.C.		98	109	109	98	414

F= Forage, G= Grain, and M= Green Manure management levels.
In each column numbers with the same letter are not different (α=0.05).

were more marked, showing the interaction of legume water use and recharge of the soil water profile during this period. In the 30-60 cm depth Fallow had more water than the Peas under Grain and Green Manure management, and even some soybean treatments had more water than the pea Grain management (Grain and Green Manure). The differences tended to decrease with depth, but in the lower part of the profile the Pea for Grain had even less water than Fallow. (Table 2.9)

d) At wheat planting the total soil water content in the 0-120 cm depth ranged from 249 to 348 mm (Fig 2.7), with the estimated plant available water ranging from 101 to 200 mm. (Table 2.9)

No significant differences were detected among legumes in terms of soil water in the whole profile (α=0.05). Fallow did have more soil water than Asgrow 2301 and Profi pea for Grain, the two treatments with the lowest water levels. There were no significant differences in the 0-30cm depth. Asgrow 2301 for Grain and for Green Manure had less water than Fallow in the 30-60cm depth. Profi pea for Grain had less water than Fallow in the two lower depths (60-120cm). Austrian winter pea for Grain had less water than Fallow in the 90-120cm layer; differences that were already present at Soybean forage harvest.

2000

a) The initial moisture determinations in the spring showed slightly lower water content in Austrian winter pea plots (22 mm) than in other treatments. The differences between the water content in the upper (0-60 cm) and lower (90-120 cm) layers were less pronounced than in the previous two years. (Table 2.10)

b) At pea forage harvest Fallow and soybean treatments had more soil water than the pea plots. Profi pea had more soil water than Austrian winter pea. The same pattern was present at all soil depths with slightly less pronounced differences in the upper layers (0-60 cm). (Table 2.10)

Table 2.10 – Total soil water content at different dates during the legume growing season in 2000.

Crop		DEPTH (cm) 0-30	30-60	60-90	90-120	Total
		mm of water				
		Legume Planting (March 29th, 2000)				
Austrian w. pea		90	90	73	59	312
All other plots		90	95	82	65	333
		Pea Forage Harvest (June 14-19th, 2000)				
Fallow		89 a	83 ab	64 a	68 a	304 a
Asgrow 2602		91 a	93 a	66 a	61 a	310 a
Asgrow 3901		86 ab	93 a	64 a	61 a	303 a
Profi pea		73 b	75 b	61 a	61 a	270 b
Austrian w. pea		54 c	57 c	46 b	49 b	206 c
F test		17.03	30.78	18.4	9.85	49.70
p-value		0.000	0.000	0.000	0.000	0.000
		Soybean Forage Harvest (Aug. 15th, 2000)				
Fallow		101 a	85 a	65 a	76 a	326 a
Asgrow	F	96 ab	74 ab	54 abcd	58 abc	282 a
2602	G	88 ab	87 a	66 a	61 ab	301 a
	M	95 ab	87 a	62 ab	62 ab	305 a
Asgrow	F	94 ab	85 a	62 ab	59 ab	300 a
3901	G	92 ab	86 a	61 ab	59 ab	299 a
	M	96 ab	85 a	59 abc	61 ab	301 a
	F	95 ab	77 ab	50 bcde	55 abc	277 a
Profi pea	G	64 c	52 c	39 e	37 d	192 b
	M	94 ab	65 abc	52 abcd	60 ab	271 a
Austrian	F	77 abc	57 bc	43 de	49 bcd	226 b
Winter	G	72 bc	56 bc	40 e	42 cd	210 b
Pea	M	73 bc	62 bc	48 cde	45 bcd	228 b
F test		5.86	8.20	12.33	8.64	16.07
p-value		0.000	0.000	0.000	0.000	0.000
		Wheat Planting (Oct. 17th, 2000)				
Fallow		99 ab	80 a	60 a	73 a	311 a
Asgrow	F	99 ab	63 abcd	47 bcd	52 bc	261 abcd
2602	G	74 c	58 bcd	42 bcd	45 bc	219 bcde
	M	97 abc	82 a	56 ab	56 ab	291 ab
Asgrow	F	93 abc	76 ab	55 ab	52 bc	276 abc
3901	G	77 c	59 bcd	44 bcd	46 bc	225 bcde
	M	99 abc	81 a	55 ab	54 ab	289 ab
	F	90 bc	68 abc	47 bcd	51 bc	255 bcde
Profi pea	G	79 abc	47 d	36 d	35 c	197 e
	M	103 a	66 abcd	49 abc	54 ab	272 abc
Austrian	F	82 abc	49 cd	39 cd	44 bc	214 cde
Winter	G	80 abc	51 cd	36 cd	38 bc	206 cde
Pea	M	78 bc	55 bcd	44 bcd	41 bc	218 bcde
F test		4.23	7.91	8.58	7.36	11.54
p-value		0.002	0.000	0.000	0.000	0.000
Estimated W.P.		37	35	27	27	126
Estimated F.C.		104	98	82	82	366

F= Forage, G= Grain, and M= Green Manure management levels. In each column numbers with the same lowercase letter are not different (α=0.05).

c) At Soybean forage harvest, only Profi pea for Grain and Austrian winter pea (all management levels) had lower soil water contents in the 0-120 cm depth than Fallow and the other legume treatments. The effect of legumes on soil water content was visible at all soil depths, but was significantly related to Fallow, only in Profi pea for Grain and Austrian winter pea (all management levels). Compared to the other legume treatments, only Profi pea for Grain had less soil water in the 0-30 cm depth. At the other depths the two peas for Grain management had less water than most of the soybeans. (Table 2.10)

d) At wheat planting the soil water content ranged from 197 mm to 311 mm (Fig.2.7), with the estimated plant available water content ranging from 71 to 185 mm. All Austrian winter pea management levels and all legume Grain levels had less water than Fallow. All legumes had higher soil water content in the Green Manure level compared to grain, but only in soybean was the difference significant. (Table 2.10)

In the 0-30 cm depth there were no significant differences between Fallow and legume treatments. Only Profi pea for Green Manure had more soil water than the soybean for Grain. In the 30-60 cm depth Fallow had more soil water than Profi pea for Grain and all Austrian winter pea levels. In the 60-120 cm depth, Fallow had more soil water than all Austrian winter pea levels and all legume Grain management levels showing that the lack of differences in the surface was due to rainfall recharge. (Table 2.10)

Wheat 1998-99

The total soil water content at the four depths measured at wheat tillering-boot stage and wheat harvest is presented in Table 2.11.

At tillering and boot stage the total water content in 0-120 cm ranged from 233 to 279 mm, showing an increase from the time of wheat planting. Only Austrian winter pea (all management levels), and Asgrow 2301 for Grain had less soil water than Fallow. While the soybean had less soil water in the whole profile, showing small non-significant

Table 2.11 – Total soil water content at different dates during wheat growth in 1999.

Crop		0-30	30-60	60-90	90-120	Total
		DEPTH (cm)				
		mm of water				
		2/3 tillers-boot (April 20th-May 14th, 1999)				
Fallow		85 ns	79 a	59 ns	52 a	275 a
Asgrow	F	91 ns	71 ab	51 ns	48 ab	260 ab
2001	G	89 ns	65 ab	47 ns	45 ab	247 ab
soybean	M	92 ns	62 ab	51 ns	53 ab	258 ab
Asgrow	F	88 ns	70 ab	58 ns	53 ab	269 ab
2301	G	81 ns	59 ab	47 ns	47 ab	234 b
soybean	M	84 ns	63 ab	50 ns	47 ab	244 ab
	F	89 ns	64 ab	47 ns	45 ab	248 ab
Profi pea	G	86 ns	66 ab	51 ns	47 ab	249 ab
	M	84 ns	78 ab	61 ns	55 a	279 a
Austrian	F	83 ns	57 b	50 ns	48 ab	239 b
Winter	G	80 ns	59 b	51 ns	43 b	233 b
Pea	M	76 ns	65 ab	52 ns	46 ab	239 b
F test		1.70	2.07	1.86	3.18	2.97
p-value		0.100	0.046	0.074	0.002	0.006
		Harvest (July 7th, 1999)				
Fallow		62 ns	57 ns	44 ab	44 ns	207 ns
Asgrow	F	57 ns	50.ns	38 b	40 ns	186 ns
2001	G	60 ns	53.ns	42 ab	45 ns	200 ns
soybean	M	67 ns	52 ns	45 ab	51 ns	214 ns
Asgrow	F	64 ns	52 ns	43 ab	46 ns	204 ns
2301	G	62 ns	54 ns	45 ab	45 ns	205 ns
soybean	M	63 ns	51 ns	45 ab	45 ns	204 ns
	F	62 ns	55 ns	42 ab	43 ns	200 ns
Profi pea	G	63 ns	53 ns	43 ab	43 ns	199 ns
	M	59 ns	56 ns	38 b	43 ns	196 ns
Austrian	F	63 ns	52 ns	46 ab	48 ns	209 ns
Winter	G	61 ns	59 ns	52 a	44 ns	216 ns
Pea	M	56 ns	53 ns	44 ab	42 ns	195 ns
F test		0.62	0.48	2.44	1.61	0.83
p-value		0.807	0.913	0.019	0.123	0.619
Estimated W.P.		35	39	39	35	148
Estimated F.C.		98	109	109	98	414

F= Forage, G= Grain, and M= Green Manure management levels. In each column numbers with the same lowercase letter are not different (α=0.05).

differences with Fallow mainly in the 30-60 cm depth. Austrian winter pea for Grain had less water than Fallow even in the 90-120 cm layer. (Table 2.11)

At wheat harvest the soil water content was fairly uniform, ranging from 196 to 216 mm without significant differences among treatments. (Table 2.11)

Wheat 1999-2000

At tillering the total soil water content ranged from 263 to 326 mm (Table 2.12). Almost all treatments lost soil water, except those which had low soil moisture at wheat planting. There were no significant differences in any soil layer, but slightly lower values in each layer indicated that Grain management levels had less water than Forage management levels in all legumes. There were no differences with Fallow. (Table 2.12)

At wheat grain harvest the soil water content ranged from 162 to 220 mm without significant differences related to the treatments studied. (Table 2.12)

6. WHEAT DRY MATTER PRODUCTION AND NITROGEN CONTENT

Wheat early growth stages

The wheat crop emerged normally and went through two mild winters. The absence of weed pressure during spring in both years made herbicide applications unnecessary.

Table 2.13 shows the mean dry matter production and N content of the wheat at early growth stages during 1999 and 2000. In 1999 the samples were collected on different growth stages, 2-3 tillers and boot stages. In 2000, the samples were collected on 2-3 tiller wheat growth stage only.

1999

All factors studied (legume, management of the legume, and fertilizer) affected the wheat dry matter production at tillering (Table 2.14). The legume x management

Table 2.12 – Total soil water content at different dates during wheat growth in 2000.

Crop		DEPTH (cm) 0-30	30-60	60-90	90-120	Total
		mm of water				
		2/3 tillers (April 17th, 2000)				
Fallow		70 ns	93 ns	76 ns	64 ns	304 ab
Asgrow	F	83 ns	82 ns	67 ns	59 ns	290 a
2001	G	73 ns	84 ns	60 ns	55 ns	271 bc
	M	75 ns	97 ns	74 ns	59 ns	306 ab
Asgrow	F	79 ns	100 ns	88 ns	60 ns	326 a
2301	G	79 ns	85 ns	58 ns	49 ns	271 bc
	M	76 ns	78 ns	63 ns	56 ns	274 ab
	F	74 ns	98 ns	80 ns	66 ns	319 a
Profi pea	G	79 ns	85 ns	67 ns	54 ns	285 bc
	M	80 ns	89 ns	76 ns	62 ns	306 ab
Austrian	F	80 ns	96 ns	81 ns	63 ns	320 a
Winter	G	77 ns	80 ns	58 ns	48 ns	264 bc
Pea	M	81 ns	91 ns	76 ns	60 ns	308 ab
F test		1.19	1.65	1.63	1.12	3.79
p-value		0.320	0.113	0.240	0.373	0.031
		Harvest (July 5th, 2000)				
Fallow		56 ns	55 ns	41 ns	39 ns	192 ns
Asgrow	F	50 ns	45 ns	35 ns	35 ns	165 ns
2001	G	57 ns	56 ns	41 ns	39 ns	193 ns
	M	58 ns	58 ns	39 ns	38 ns	192 ns
Asgrow	F	67 ns	65 ns	47 ns	42 ns	221 ns
2301	G	60 ns	57 ns	41 ns	44 ns	202 ns
	M	53 ns	47 ns	39 ns	39 ns	177 ns
	F	60 ns	60 ns	45 ns	41 ns	206 ns
Profi pea	G	52 ns	50 ns	38 ns	33 ns	171 ns
	M	53 ns	52 ns	42 ns	37 ns	183 ns
Austrian	F	61 ns	58 ns	41 ns	41 ns	201 ns
Winter	G	50 ns	46 ns	33 ns	33 ns	162 ns
Pea	M	59 ns	55 ns	41 ns	39 ns	194 ns
F test		0.87	1.37	1.01	0.87	1.45
p-value		0.582	0.218	0.461	0.577	0.179
Estimated W.P.		35	39	39	35	148
Estimated F.C.		98	109	109	98	414

F= Forage, G= Grain, and M= Green Manure management levels. In each column numbers with the same letter are not different (α=0.05).

Table 2.13 – Wheat dry matter production, N content, and N uptake at tillering and booting stages in 1999 and at tillering in 2000. (See Table 2.14 for ANOVA).

		YEAR: 1999 (N level)		2000 (N level)	
		0N	40N	0N	40N
Fallow	DM (kg ha^{-1})	1296	1648	835	1020
	N conc (g kg^{-1})	35.4	37.8	36.8	39.1
	N uptk(kg ha^{-1})	45.9	62.3	30.7	39.9

Crop	Parameter	1999 Management Level: Forage (N level)		Grain (N level)		Green Manure (N level)		2000 Management Level: Forage (N level)		Grain (N level)		Green Manure (N level)	
		0N	40N	0N	40N	0N	40N	0N	40N	0N	40N	0N	40N
Austrian Winter Pea	DM (kg ha^{-1})	1033	1196	915	1152	1309	1405	763	943	577	718	695	871
	N conc (g kg^{-1})	34.0	36.5	30.5	34.9	33.4	37.4	33.6	38.5	40.0	43.9	39.8	45.7
	N uptk(kg ha^{-1})	35.1	43.7	27.9	40.2	43.7	52.6	25.6	35.9	22.9	31.3	27.6	39.7
Profi pea	DM (kg ha^{-1})	1084	1202	910	1227	1220	1531	756	915	533	645	646	811
	N conc (g kg^{-1})	34.0	40.1	28.6	32.8	31.0	34.6	32.8	39.1	30.2	39.4	33.9	40.4
	N uptk(kg ha^{-1})	36.9	48.2	26.0	40.2	37.8	53.0	24.8	36.3	16.3	25.8	22.1	33.5
Soybn 1 (a)	DM (kg ha^{-1})	894	875	518	567	1009	1281	659	730	543	702	538	810
	N conc (g kg^{-1})	36.5	40.7	39.6	42.9	35.0	39.3	39.1	41.5	36.8	42.8	37.1	44.2
	N uptk(kg ha^{-1})	32.6	35.6	20.5	24.3	35.3	50.3	25.6	30.5	19.6	29.8	19.9	35.4
Soybn 2 (b)	DM (kg ha^{-1})	819	944	513	616	1169	1341	698	802	450	620	481	533
	N conc (g kg^{-1})	36.2	40.1	36.6	42.8	30.2	35.5	35.7	42.5	30.1	40.1	36.1	41.6
	N uptk(kg ha^{-1})	29.6	37.9	18.8	26.4	35.3	47.6	25.4	34.4	13.5	24.7	17.6	22.5

(a) Soybean 1: Asgrow 1901, 2001 and 2602 in 1998, 1999 and 2000 respectively.
(b) Soybean 2: Asgrow 2301, 2301 and 3901 in 1998, 1999 and 2000 respectively.
DM= dry matter, N conc= N content, N uptk= N uptake.

Table 2.14 – Analysis of variance for dry matter production, N content, N uptake of wheat samples collected at tillering and boot stages of growth in 1999 and 2000. (Refer to Table 2.13).

Source of variation	YEAR 1999		2000	
	F test	P-value	F test	P-value
Wheat dry matter at tiller-boot stage (without Fallow)				
Legume	12.7	<0.0001	4.1	0.0144
Management	34.6	<0.0001	6.7	0.0035
Leg x Man	3.2	0.0147	0.9	0.5035
Fertilizer	45.8	<0.0001	66.4	<0.0001
Leg x Fert	1.0	0.3890	0.3	0.8064
Man x Fert	2.9	0.0681	1.0	0.3860
Leg x Man x Fert	1.8	0.296	1.2	0.3513
Wheat dry matter at tiller-boot stage (with Fallow)				
Treatment	15.0	<0.0001	4.3	0.0002
Fertilizer	43.3	<0.0001	55.5	<0.0001
Treat x Fert	1.4	0.2006	0.6	0.8317
Wheat N uptake at tiller-boot stage (without Fallow)				
Legume	3.3	0.0309	4.8	0.0072
Management	22.8	<0.0001	5.2	0.0111
Leg x Man	0.8	0.5613	1.2	0.3558
Fertilizer	67.2	<0.0001	213.2	<0.0001
Leg x Fert	1.1	0.3512	0.3	0.8270
Man x Fert	1.1	0.3565	2.5	0.0959
Leg x Man x Fert	0.9	0.4841	2.5	0.0410
Wheat N uptake at tiller-boot stage (with Fallow)				
Treatment	9.6	<0.0001	3.7	0.0007
Fertilizer	75.8	<0.0001	133.2	<0.0001
Treat x Fert	0.9	0.5458	1.1	0.4086

interaction, although significant, was not considered in the mean comparisons because of its small effect compared to the main effects ($p=0.015$ vs $p<0.0001$).

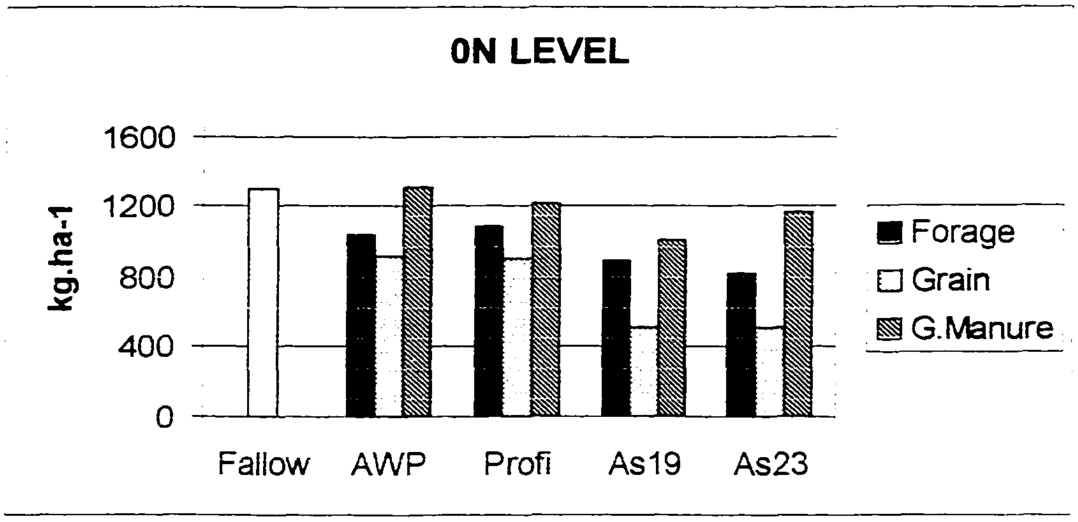
Averaging across management levels, wheat after pea produced more dry matter than after soybean, with wheat after Profi pea producing more dry matter than after Austrian winter pea (Fig.2.8). Averaging across legume management levels, wheat after legumes for Green Manure had more dry matter than after legumes for Forage, and both of these exceeded wheat biomass after legumes for Grain production. Nitrogen fertilization of the wheat increased the biomass production about 118 kg ha^{-1}.

Averaging across management levels, wheat after Fallow produced more dry matter than wheat after pea ($p=0.0003$) and after soybean ($p<0.0001$). Regarding management effects, the differences between the Fallow control and the Green Manure legumes treatments (155 kg ha^{-1}) were not significant at $\alpha=0.05$ level.

Wheat N uptake showed effects of management and legume types with no significant interactions. The wheat after legumes for Green Manure had a higher N uptake than after legumes for Forage, and these higher than after legumes for Grain. Fertilization increased the N uptake. The N uptake of the wheat after Fallow was not significantly different from the uptake after legumes for Green Manure ($\alpha=0.05$).

2000

All factors had significant effects on wheat biomass at tilllering without significant interactions (Table 2.14) Averaging across legume levels, the wheat after legumes for Forage produced more biomass than legumes for Green Manure or Grain (Fig.2.9). Averaging across management levels, wheat after Austrian winter pea produced more biomass than after Asgrow 2301 soybean. The two other legumes produced an intermediate effect on wheat biomass. Nitrogen fertilization increased wheat biomass production.



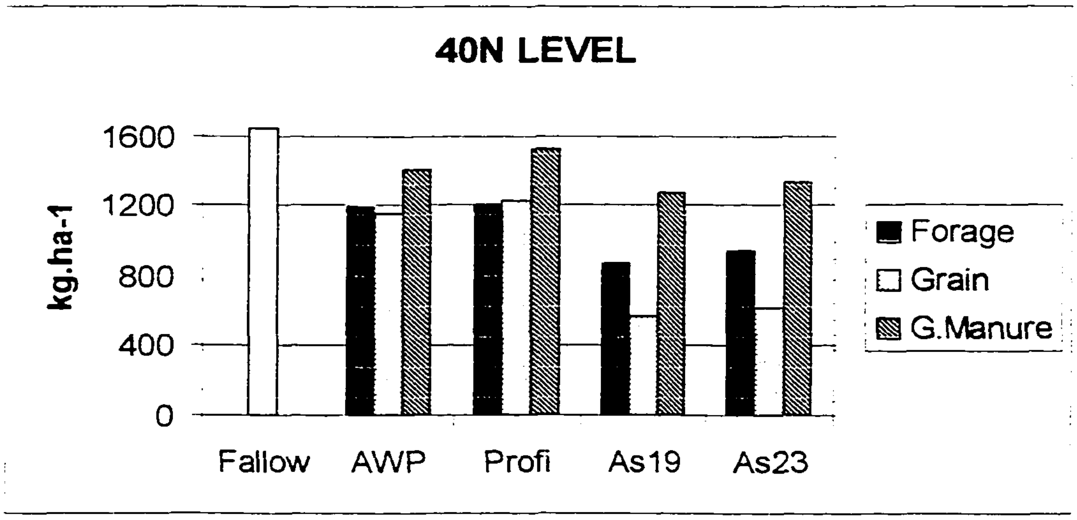
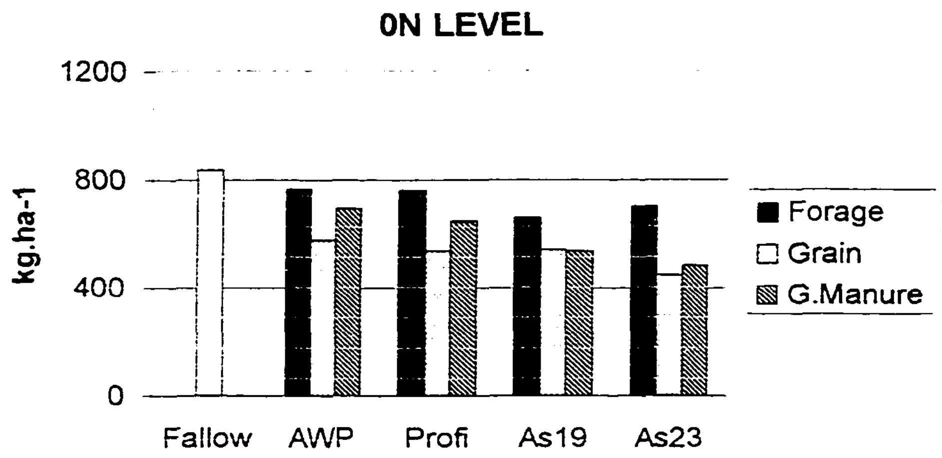


Fig. 2.8 – Wheat biomass production at the 2-3 tiller and boot stages of growth in 1999.



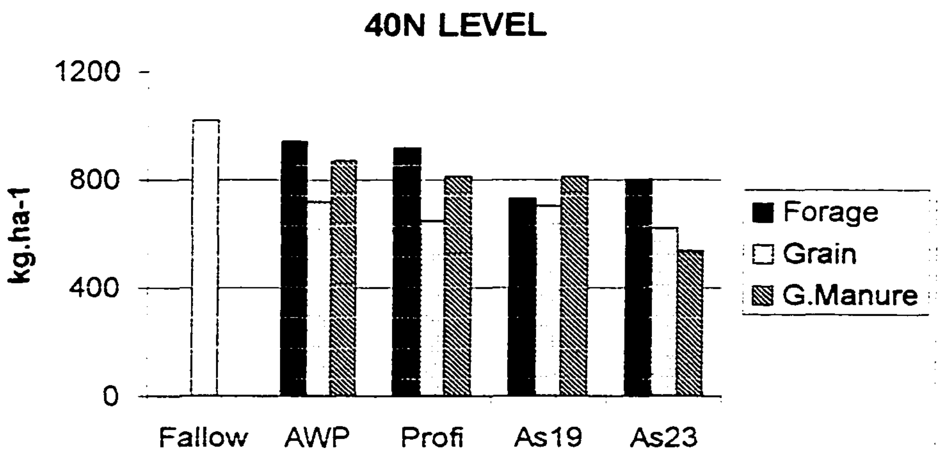


Fig. 2.9 – Wheat biomass production at the 2-3 tiller growth stage in 2000.

The wheat after Fallow produced more biomass than wheat after all legumes for Grain management (except Austrian winter pea), and after Asgrow 2301 soybean for Green Manure. The wheat biomass in the control treatment was not different from that following pea for Forage, but higher than the biomass after soybean for Forage.

The N uptake by wheat was affected by the three factors studied, without interactions. Averaging across management levels, the wheat after Austrian winter pea had a higher N uptake than after Asgrow 2301 soybean, with the other legume treatments being intermediate. Wheat after legumes for Forage had higher N uptake than after legumes for Grain, with Green Manure being intermediate. Fertilization increased the wheat N uptake.

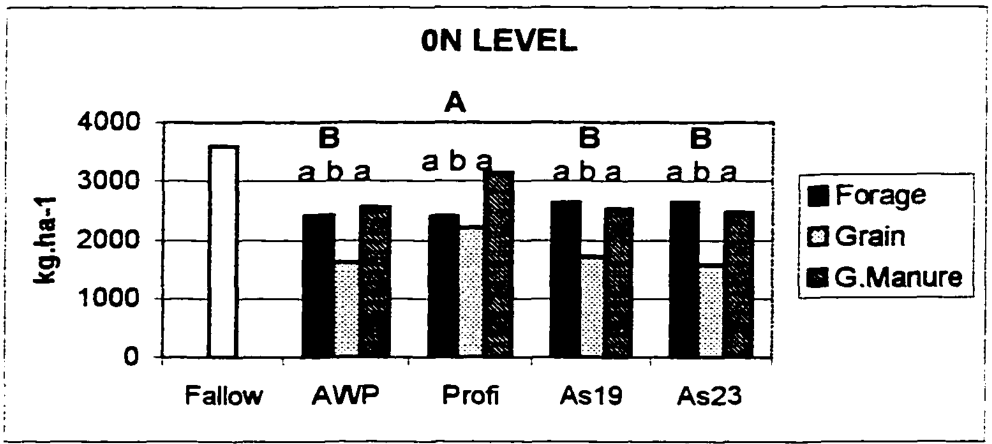
The wheat after Fallow had a higher N uptake than wheat after Profi pea for Grain, and after Asgrow 2301 soybean for Grain and Green Manure. The other treatments were not significantly different from Fallow at α=0.05 level.

Wheat maturity

1999

The wheat grain yield, expressed at a grain moisture content of 12.5%, ranged from 1568 to 3712 kg.ha^{-1} in 1999 (Fig. 2.10 and Table 2.15).

All factors studied (legume, legume management and fertilizer) had significant effects on wheat grain yield (Table 2.16). The fertilizer factor showed a borderline interaction with legume but was not considered in the mean comparisons due to its reduced significance related to the main effects. The interaction was caused by the wheat after Austrian winter pea and the soybean responding slightly, or not at all, to N fertilization, while the wheat after Profi pea showed a greater response. Despite a significant fertilizer effect the average wheat response was small (121 kg ha^{-1}), except for the wheat after Profi pea.



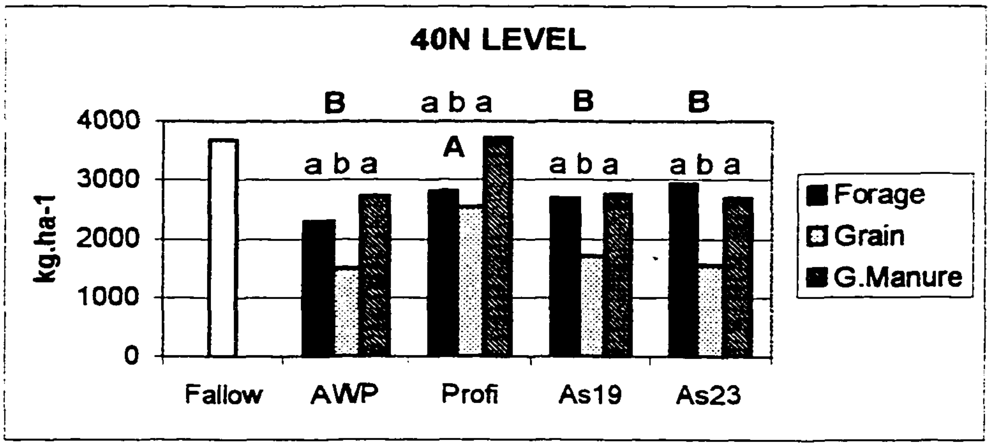


Fig. 2.10 – Wheat grain production in 1999. Capital letters show differences across management levels. Small letters show differences across legume levels (α=0.05).

Table 2.15 – Wheat grain and residue yield and N content in 1999.

		FERTILIZER	
		0N	40N
Fallow	Grain (kg ha^{-1})	3600	3682
	Res (kg ha^{-1})	5590	6277
	Ng (g kg^{-1})	22.5	25.5
	Nres (g kg^{-1})	4.8	5.9
	Nupg (kg ha^{-1})	81	93
	Nupr (kg ha^{-1})	27	37
	Nuptot (kg ha^{-1})	108	130

		MANAGEMENT LEVELS					
		Forage		Grain		Green Manure	
		N Level		N Level		N Level	
		0N	40N	0N	40N	0N	40N
Austrian Winter Pea	Grain (kg ha^{-1})	2422	2290	1623	1504	2551	2729
	Res (kg ha^{-1})	3790	3906	3120	3382	4720	5593
	Ng (g kg^{-1})	22.7	24.8	21.3	26.6	20.9	28.2
	Nres (g kg^{-1})	4.8	5.5	4.1	6.5	4.4	7.8
	Nupg (kg ha^{-1})	54	56	35	40	52	77
	Nupr (kg ha^{-1})	18	22	13	22	21	44
	Nuptot (kg ha^{-1})	72	78	48	62	73	121
Profi pea	Grain (kg ha^{-1})	2411	2806	2219	2544	3144	3712
	Res (kg ha^{-1})	4150	5220	3667	4281	4719	6296
	Ng (g kg^{-1})	23.3	25.7	18.0	21.8	20.0	22.3
	Nres (g kg^{-1})	5.3	5.9	3.3	4.4	4.0	4.5
	Nupg (kg ha^{-1})	56	72	40	54	64	82
	Nupr (kg ha^{-1})	24	31	12	18	19	29
	Nuptot (kg ha^{-1})	80	103	52	72	83	111
Asgrow 1901 soybn	Grain (kg ha^{-1})	2633	2692	1712	1709	2528	2760
	Res (kg ha^{-1})	3667	4186	2981	3108	4275	4277
	Ng (g kg^{-1})	21.3	22.9	23.6	27.4	24.5	28.2
	Nres (g kg^{-1})	4.4	5.4	4.9	6.8	5.7	7.3
	Nupg (kg ha^{-1})	56	62	39	47	62	78
	Nupr (kg ha^{-1})	16	23	14	21	24	31
	Nuptot (kg ha^{-1})	72	85	53	68	86	109
Asgrow 2301 soybn	Grain (kg ha^{-1})	2653	2940	1568	1561	2474	2686
	Res (kg ha^{-1})	4141	4709	2445	2887	4007	4278
	Ng (g kg^{-1})	24.3	25.0	24.2	27.4	24.0	25.6
	Nres (g kg^{-1})	5.7	6.2	5.4	7.3	5.3	6.5
	Nupg (kg ha^{-1})	63	73	38	43	58	67
	Nupr (kg ha^{-1})	23	29	13	21	21	28
	Nuptot (kg ha^{-1})	86	102	51	64	79	95

Grain= grain yield, Res= residue yield, Ng=grain N content, Nres=N content in residues, Nupg=N uptake by grain, Nupr=N uptake by residues, Nuptot= total N uptake.

Table 2.16 – Analysis of variance for grain yield, residue yield, grain N uptake and residue N uptake for the wheat samples collected at harvest in 1999. (Refer to Table 2.15).

Source of Variation	F test	P-value	F test	P-value
	Grain yield		**Residue yield**	
Legume	6.2	0.0018	4.4	0.0105
Management	37.9	<0.0001	20.6	<0.0001
Leg x Man	1.6	0.1921	0.9	0.5149
Fertilizer	5.7	0.0225	14.6	0.0005
Leg x Fert	2.6	0.0698	1.6	0.2014
Man x Fert	1.2	0.3109	0.0	0.9987
Leg x Man x Fert	0.3	0.9228	0.42	0.8626
	Grain yield with Fallow		**Residue yield with Fallow**	
Treatment	18.4	<0.0001	10.9	<0.0001
Fertilizer	7.1	0.0104	20.6	<0.0001
Treat x Fert	1.2	0.2849	0.8	0.6893
	Grain N uptake		**Residue N uptake**	
Legume	1.6	0.2000	0.2	0.8670
Management	32.3	<0.0001	13.9	<0.0001
Leg x Man	0.5	0.8183	1.5	0.2122
Fertilizer	58.3	<0.0001	51.5	<0.0001
Leg x Fert	1.7	0.1855	0.4	0.7520
Man x Fert	2.0	0.1503	1.0	0.3626
Leg x Man x Fert	0.9	0.4954	0.6	0.7082
	Grain N uptake with Fallow		**Resid. N uptake with Fallow**	
Treatment	14.0	<0.0001	6.0	<0.0001
Fertilizer	64.5	<0.0001	63.4	<0.0001
Treat x Fert	1.3	0.2784	0.7	0.7873

Averaging across management levels, wheat after Profi pea yielded more grain than wheat after all other legumes. Averaging across legume types the wheat after legumes managed for Grain yielded less than wheat after legumes managed for Forage or Green Manure. Wheat after Fallow produced more grain than wheat after pea or soybean (under any management). The only treatment with wheat yield not significantly different from those after Fallow was Profi pea for Green Manure ($p<0.05$) (Table 2.15).

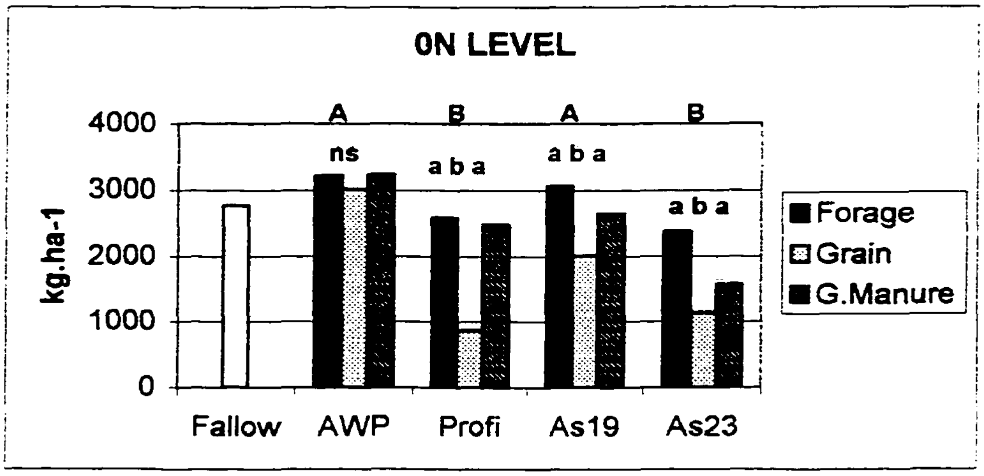
Wheat residue yield was affected by the three factors studied, without significant interactions. Averaging across management levels wheat after Profi pea produced more residue than after soybean, with residues after Austrian winter pea being intermediate. Averaging across legume types wheat after legumes for Green Manure produced more residues than after legumes for Forage, and these more than after legumes for Grain. Wheat after Fallow produced more residues than wheat after legumes, except wheat after Profi for Forage and Green Manure and Austrian winter pea for Green Manure.

The N uptake in wheat grain and residues responded similarly to the treatments. The effect of the legume factor on both variables was non-significant. Total wheat N uptake (grain plus residues) after legumes for Forage or Green Manure was higher than after legumes for Grain. Nitrogen fertilization increased N uptake both in grain and residues.

The N uptake of the wheat after most of the legumes was lower than after Fallow. The exceptions were Profi pea and Asgrow 1901 soybean for Green Manure management, and all legumes for Green Manure plus some for Forage management (Profi pea and Asgrow 2301) in wheat residues.

2000

The wheat grain yield in the 2000 harvest ranged from 870 to 3568 kg ha^{-1} (Fig.2.11 and Table 2.17). Because of significant interactions between the two factors in the main plot (legume and management) with the fertilizer factor in the split-plots.



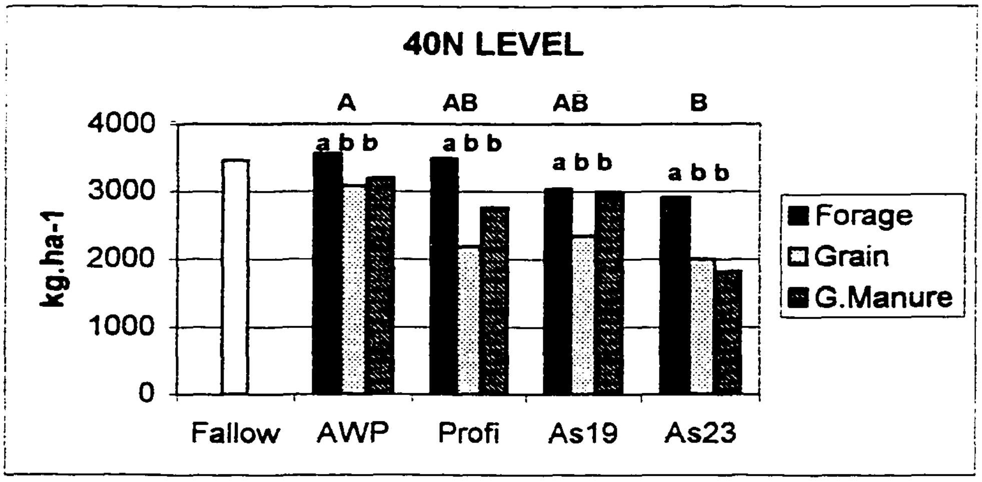


Fig. 2.11 – Wheat grain production as affected by residue management and cropping system in 2000. Capital letters show differences across management levels. Small letters show differences across legume levels (α=0.05).

Table 2.17 – Wheat grain, residue yield, N content and uptake in 2000.

		FERTILIZER	
		0N	40N
Fallow	Grain (kg ha^{-1})	2768	3466
	Res (kg ha^{-1})	5781	8052
	Ng (g kg^{-1})	22.1	24.6
	Nres (g kg^{-1})	5.5	5.6
	Nupg (kg ha^{-1})	62	84
	Nupr (kg ha^{-1})	33	44
	Nuptot (kg ha^{-1})	95	128

		MANAGEMENT LEVEL					
		Forage		Grain		Green Manure	
		N Level		N Level		N Level	
		0N	40N	0N	40N	0N	40N
Austrian Winter Pea	Grain (kg ha^{-1})	3205	3568	3015	3086	3230	3197
	Res (kg ha^{-1})	7226	8765	7254	7418	7838	8445
	Ng (g kg^{-1})	21.3	25.6	25.8	27.2	25.7	27.1
	Nres (g kg^{-1})	5.3	7.2	6.9	7.8	6.2	7.6
	Nupg (kg ha^{-1})	68	89	78	84	83	86
	Nupr (kg ha^{-1})	37	59	48	56	49	66
	Nuptot (kg ha^{-1})	105	148	126	140	132	152
Profi pea	Grain (kg ha^{-1})	2585	3493	870	2188	2473	2758
	Res (kg ha^{-1})	5805	8046	1747	5124	4954	5843
	Ng (g kg^{-1})	22.3	23.7	19.7	22.6	21.9	23.6
	Nres (g kg^{-1})	5.2	5.8	6.4	6.3	6.0	6.4
	Nupg (kg ha^{-1})	58	83	18	50	55	66
	Nupr (kg ha^{-1})	31	46	12	32	31	38
	Nuptot (kg ha^{-1})	89	129	30	82	86	104
Asgrow 2001 soybean	Grain (kg ha^{-1})	3068	3041	2006	2345	2637	2988
	Res (kg ha^{-1})	6067	6571	5194	5861	4999	9710
	Ng (g kg^{-1})	24.6	25.3	25.6	28.0	23.8	25.1
	Nres (g kg^{-1})	5.4	5.7	7.0	8.1	6.2	6.2
	Nupg (kg ha^{-1})	75	77	53	65	62	74
	Nupr (kg ha^{-1})	32	37	37	47	31	64
	Nuptot (kg ha^{-1})	107	114	90	112	93	138
Asgrow 2301 soybean	Grain (kg ha^{-1})	2371	2906	1127	1992	1572	1810
	Res (kg ha^{-1})	5162	7327	2320	4960	2913	3572
	Ng (g kg^{-1})	23.3	24.9	24.5	26.4	24.9	24.0
	Nres (g kg^{-1})	5.8	6.2	6.1	7.3	6.5	6.7
	Nupg (kg ha^{-1})	56	73	28	53	38	43
	Nupr (kg ha^{-1})	31	46	13	37	17	20
	Nuptot (kg ha^{-1})	87	119	41	90	55	63

Grain= grain yield, Res= residue yield, Ng=grain N content, Nres=N content in residues, Nupg=N uptake by grain, Nupr=N uptake by residues, Nuptot= total N uptake.

independent analysis of variance were performed for each of the fertilizer levels (Table 2.18).

At the 0N level both legume and management factors affected the wheat grain yield, with a legume x management interaction. The wheat yield after Austrian winter pea did not vary with the legume management level, while in all other legumes the wheat after Forage or Green Manure management yielded more than after Grain management. Averaging across management levels, wheat after Austrian winter pea and Asgrow 2001 soybean yielded more than after Profi pea or Asgrow 2301 soybean. At this fertilizer level, the wheat after Fallow yielded more than wheat after Profi pea for Grain, and after Asgrow 2301 soybean for Grain and Green Manure.

At the 40N level both main effects were significant without interactions. Averaging across management levels the wheat after Austrian winter pea yielded more than after Asgrow 2301 soybean, with other levels being intermediate. Averaging across legume types, wheat after legumes for Forage yielded more than after legumes for either Green Manure or Grain. The wheat yield after Fallow was higher than after all legumes for Grain (except the wheat after Austrian winter pea), and than wheat after Profi pea and Asgrow 2301 soybean for Green Manure.

Residue yield of wheat (Table 2.17) was highly affected by the three factors with a less significant interaction between legume type and management. Averaging across management levels the production of residues after Austrian winter pea was higher than after Asgrow 2301 soybean, and the other legume types were intermediate. Averaging across legume types, wheat after legumes for Forage produced more residues than after legumes for either Grain or Green Manure. Nitrogen fertilization increased residue production. The wheat after Fallow produced more residues than wheat after Profi pea for Grain and after Asgrow 2302 soybean for Grain and Green Manure.

Table 2.18 – Analysis of variance for grain yield, residue yield, grain N uptake and residue N uptake for the wheat samples collected at harvest in 2000. (Refer to Table 2.17).

Source of variation	F test	P-value	F test	P-value
	Grain yield		**Residue yield**	
Legume	9.3	<0.0001	11.5	<0.0001
Management	12.1	<0.0001	8.5	0.0010
Leg x Man	2.3	0.0607	2.7	0,0299
Fertilizer	20.7	<0.0001	30.2	<0.0001
Leg x Fert	5.0	0.0054	3.1	0.0372
Man x Fert	7.3	0.0021	3.2	0.0503
Leg x Man x Fert	2.1	0.0785	3.0	0.0191
	Grain yield 0N		**Grain yield 40N**	
Legume	12.0	<0.0001	4.4	0.0104
Management	15.6	<0.0001	5.9	0.0062
Leg x Man	3.1	0.0168	1.3	0.2686
	Grain with Fallow		**Residue yield with Fallow**	
Treatment	7.1	<0.0001	7.4	<0.0001
Fertilizer	25.4	<0.0001	35.7	<0.0001
Treat x Fert	3.7	0.0006	2.9	0.0047
	Grain yield with Fallow 0N		**Grain yield with Fallow 40N**	
Treatment	7.5	<0.0001	3.3	0.0028
	Grain N uptake		**Residue N uptake**	
Legume	10.8	<0.0001	9.0	0.0002
Management	9.1	0.0007	2.1	0.1436
Leg x Man	2.9	0.0230	2.1	0.0798
Fertilizer	34.5	<0.0001	40.5	<0.0001
Leg x Fert	4.8	0.0064	1.5	0.2282
Man x Fert	8.6	0.0009	2.7	0.0796
Leg x Man x Fert	2.7	0.0296	2.3	0.0555
	Grain N uptake 0N		**Grain N uptake 40N**	
Legume	12.8	<0.0001	5.5	0.0037
Management	1.5	<0.0001	4.7	0.0158
Leg x Man	3.8	0.0056	1.7	0.1548
	Grain N uptake with Fallow		**Residue N uptake with Fallow**	
Treatment	6.6	<0.0001	3.8	0.0006
Fertilizer	40.5	<0.0001	41.3	<0.0001
Treat x Fert	4.0	0.0003	1.8	0.0706
	Grain N uptake w/Fallow 0N		**Grain N uptake w/Fallow 40N**	
Treatment	6.4	<0.0001	3.4	0.0022

The wheat grain N uptake was strongly affected by all three main factors with highly significant interactions between both factors in the main plots and the fertilizer factor in the split-plots (Table 2.18). The analysis at the 0N level of fertilizer factor showed a higher N uptake by the wheat grain after Austrian winter pea and Asgrow 2001 soybean than after Profi pea and Asgrow 2301 soybean. Averaging across legume types the grain N uptake by wheat after legumes for Forage and Green Manure was higher than after legumes for Grain. The grain N uptake of the wheat after Fallow was higher than after Profi pea and Asgrow 2301 soybean for Grain.

At the 40N level the wheat after Austrian winter pea had higher N uptake than wheat after Profi pea and Asgrow 2301 soybean. Wheat after legumes for Forage had a higher N uptake than after legumes for Grain or for Green Manure.

The residue N uptake was affected only by legume and N fertilizer with some borderline interactions. Averaging over the management factor, only wheat residues after Austrian winter pea had more N uptake than after Asgrow 2301 soybean. Fertilization increased the N uptake by wheat residues. Only the wheat residues after Profi pea for Grain had lower N uptake than wheat after Fallow.

The total N uptake by wheat (grain plus residues) was affected by all factors, with interactions between the two factors in the main plot and the fertilizer factor in the split-plot. At the 0N level there was a significant legume x management interaction. This was caused by a marked decrease in wheat N uptake after legumes for Grain related to the other management levels in Profi pea and Asgrow 2301 soybean. After Austrian winter pea or after Asgrow 2001 soybean there were no differences in total N uptake between management levels.

At the 40N level, only the legume type produced significant effects. The wheat after Austrian winter pea had more total N uptake than after Profi pea or Asgrow 2301 soybean. The wheat after Fallow had more N uptake than after Profi pea and Asgrow

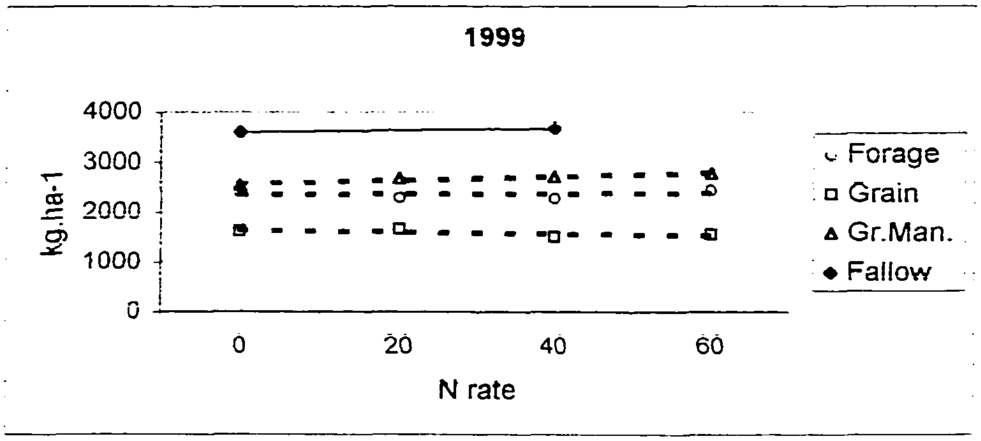
2301, both for Grain, at the 0N level. At the 40N level the wheat after Fallow had higher N uptake than the wheat after all legumes for Grain (except Austrian winter pea), and after Profi pea and Asgrow 2301 soybean both for Green Manure.

Wheat grain yield response to N fertilizer after Austrian winter pea

The wheat grain yield after Austrian winter pea was affected by the three legume management levels and the four N rates (0, 20, 40 and 60N). The data is presented in Fig. 2.12 for the two wheat seasons (1999 and 2000), and is compared to the wheat yield after Fallow. The dotted lines represent a linear regression fit for each management level; since Fallow included only two N rates (0 and 40), the full line connects those points showing a tentative relationship with the other treatments.

In 1999 the wheat yield after Fallow was higher than after the legume in all management levels (α=0.05). The wheat yield after the Forage and Green Manure levels was not different but both were higher than after Grain. The yield response to the increasing N rate was not significant (p=0.710).

In 2000, the yield after the legume (all management levels) was slightly higher than the yield after Fallow at the 0N level. However, the effect of management and fertilizer factors on wheat yield were not significant (p=0.455 and p=0.589 respectively). When compared to fallow (only in 0 and 40N levels), there were no significant effects of legume management (0.956) or the fertilizer factor (0.205).



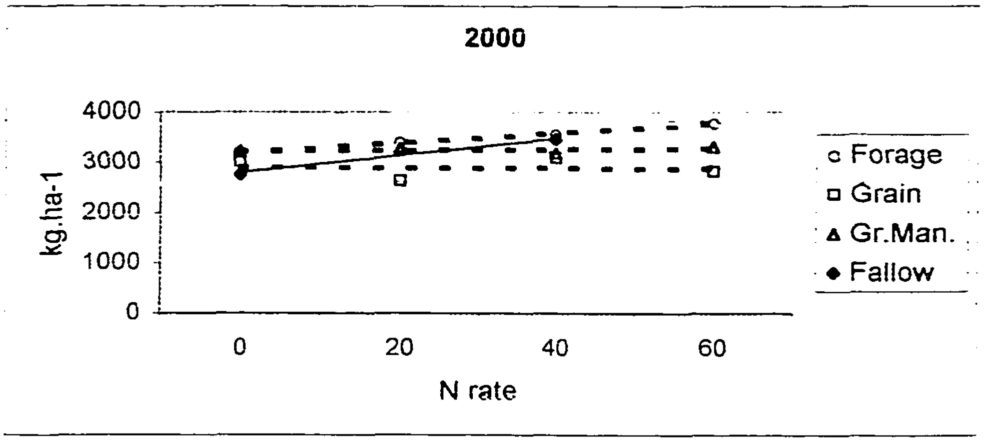


Fig. 2.12 – Wheat grain response to N fertilizer after Austrian winter pea with differing legume management.

Chapter 3

DISCUSSION

1. Weather conditions

The climatic conditions varied widely during the study period. Two of three summers (1998 and 2000) were dry during the first part of the summer fallow with rainfall below the long-term average (28 and 58% respectively), but near average during July, August and September (112 and 108%). During one of the summers (1999) precipitation greatly exceeded the normal during the entire summer fallow period, which is unusual. If more rainfall in late summer is frequent, a “summer” crop like soybean would have an advantage over those growing mainly in the first part of the spring/summer (pea).

The winter months during the two seasons studied were dry and very dry (81 and 48% of the long-term average), limiting the possibility of the soil planted to wheat to get recharged with water. The spring-summer months during the wheat growing season were abnormally wet (1999) and dry (2000). The combination of these periods for each wheat crop tended to compensate, since a dry pre-planting season in 1998 was followed by an average winter and a wet spring-summer. In 1999, the wet pre-planting season was followed by dry winter and spring-summer months. The higher than normal winter temperatures also aided the fall planted Austrian winter pea.

While definite conclusions in dryland usually require a long period of study, the fact that dry and wet years were represented for almost all crops assures a reasonable validity to the data.

2. Legume growth and production

Poor planting conditions (due either to hot and dry weather or failure of machines to work properly) and weeds were the two main problems found with all legumes. Similar difficulties were reported by Poss (2001) in the same area, by Power and Koerner (1994), in eastern Nebraska, and by Biederbeck et al (1993) in the Canadian prairies. The soil characteristics of the site (tendency for surface compaction in a heavily used experimental area) may have caused part of the problem. However, the inherent poor ability of the legumes to emerge with adequate plant stand, in no-till and during hot and dry weather, should also be considered and addressed in future experiments.

While Austrian winter pea and soybean were more able to compete with weeds, Austrian winter pea because of its fall planting and the soybean because of a cheap available herbicide control. Profi pea was clearly inferior in both forage and grain yields. Poss (2001) showed similar results for spring peas at two sites in eastern Colorado.

Temperature and rainfall were additional factors related to the legume growth. The dry matter production of the pea types was maximum in 1999, the wet summer year, and low in 1998 and 2000 (Fig.2.2), corresponding to the low rainfall and high temperatures for those years. In 1999, with high rainfall and slightly lower than average temperature both pea types showed better yields. Soybean had more adequate climatic conditions during its growth and were less affected, showing a more stable growth pattern.

Considering the variation in years and sites, the total dry matter production and N uptake obtained in this study compares reasonably to other data reported in similar environments. In a field experiment in Nebraska Power and Koerner (1994), reported dry matter production ranging from 1900 to 2660 kg ha^{-1} for Austrian winter pea by July 3rd to 13th (1983 through 1986), and from 1440 to 11380 kg ha^{-1} for soybeans by August 8th to 13th. Production of Austrian winter pea and soybeans averaged 2070 and 4580 kg ha^{-1}.

At two sites in eastern Colorado, Poss (2001) obtained Austrian winter pea forage yields ranging from 1270 to 3960 kg ha^{-1}. The average across sites and four years (1994 to 1997), was 3200 kg ha^{-1}, not including two failures due to seed desiccation. Vigil and Nielsen (1998) measured Austrian winter pea yields of 1700 and 4800 kg ha^{-1} in 1994 and 1995 respectively at Akron.

Averaged over three years, forage production of Austrian winter pea (1873 kg ha^{-1}) was slightly higher than for soybean (1550 kg ha^{-1}). The production of Profi pea was the lowest (831 kg ha^{-1}). Austrian winter pea is considered to be one of the most adapted species for forage production in the area (Poss, 2001), but obviously the potential for soybean forage production in this environment using the late summer rainfall also seems good.

A comparison of forage quality is probably not the best since the selection of soybean varieties was based on grain production potential. The more lignified shoots of the soybeans may make them difficult to eat by the animals unless grounded or cut early in the season when less dry matter has been produced. New soybean varieties adapted for forage production are not common, but are becaming available, with interesting potential for this environment.

The grain production of the soybean was clearly greater than that of the pea. The more favorable and stable growing conditions explain this result. The intense genetic improvement efforts devoted to soybean development probably increased the growth potential of modem cultivars relative to those of other species not subjected to such improvement efforts (Power and Koerner, 1994).

The yields obtained in this experiment should be considered carefully in relation to the farm yield potential. They were estimated from small plots and samples, sometimes with irregular stands, so the data are mainly valid on a comparison basis relative to the different treatment studied. The extrapolation to real farm situations should be supported with more information derived from special designed on-farm experiments.

An evaluation of the error involved in the root recovery from the soil (Table 1.4) shows that root dry matter was underestimated for the peas in the 0-18cm depth, and for all legumes in the 18-36cm depth. This underestimation could be as much as 31, 71, and 18 kg ha^{-1} in the 0-18cm depth, and 117, 138 and 115 kg ha^{-1} in the 18-36cm depth for Austrian winter pea, Profi pea and soybeans respectively. These results do not affect the relationships among legumes, but make the data from the 18-36 cm depth difficult to use and interpret.

The total above and below-ground dry matter production (Figs. 2.3 and 2.4) was higher for the soybean than for pea during 1998 and 2000, the dry summers, and similar in the wet year (1999).

3. N uptake and its importance to the system.

The N uptake in legumes is of special interest since part of this supply comes from biological fixation and is considered an input to the system. Different N credits have been attributed to legumes growing previous to a non-legume crop (Bundy et al, 1993). The estimation of these credits, however, produced variable results (according to the method used), and was not always confirmed by the yield of subsequent crops.

According to Holford and Crocker (1997), the potential contribution of legumes to N accretion in the soil should be closely related to vegetative yield and total N content.

If the legume biomass N that is left on or in the soil after removing the product of each treatment is considered, the legume by management combinations used in this experiment should provide different inputs for the next crop. Table 3.1 presents estimates for the N input from above and below-ground legume biomass. The inputs to the system are indicated with parenthesis in the table and the correspondent percentage, related to the total biomass N, is also presented. Some assumptions were made for this estimation. The Forage management was considered to take all the above-ground biomass during harvest; the complete Green Manure management biomass was supposed to remain in the plots (some amount of dry leaves are usually blown off, especially for the soybeans). All the grain was considered as removed in the Grain treatment. In fact, part of the grain remains in the field after a normal harvest. This is especially important with Austrian winter pea, which usually lays flat on the ground at harvest time. The soybean harvester also misses some of the lower pods if the season is dry and the crop stature is short. Also some grain shattering occurs previous or during harvest.

Data in Table 3.1 show the lower, almost negligible N inputs for the Forage management, and higher contributions from both Grain and Green Manure management levels. The Forage management relies mainly on the roots for its N input to the subsequent crop. For the pea only 13% of the total N uptake remained in the soil in the legume roots. Soybean had higher N input than pea (almost double). An underestimation of N inputs is likely in this experiment, due to the low N amounts involved in the surface layer and the comparable errors in the 18-36 cm depth, but even if the root N contribution is doubled, the amounts would be of interest only in the case of soybean. This is in disagreement with Mc Neil et al. (1997) who reported a significant proportion of legume N is located below-ground and can supply a major proportion of the N utilized by a subsequent crop. The Grain and Green Manure management, whenever grain production was obtained, provided similar N input in all legumes. The fact that the Grain crop continues to grow, while the Green Manure is killed at bloom stage, allows a "compensatory growth" that almost equals the biomass N of both treatments. This result is important when considering the practical and economic feasibility of both treatments, but further conclusions should take into account the N balance, dependent on the

Table 3.1 – N input estimates from legume above and below-ground biomass, and percentages of N input related to total biomass N for Austrian winter pea, Profi pea and soybean.

		YEAR											
		1998			1999			2000			Average		
Legume	Management	Above	Below	Input	Above	Below	Input	Above	Below	Input	Above	Below	Input
		--- kg N ha^{-1} ---		-- % --	--- kg N ha^{-1} ---		-- % --	--- kg N ha^{-1} ---		-- % --	--- kg N ha^{-1} ---		-- % --
Austrian winter pea	Forage	41	(6)	13	91	(14)	13	57	(9)	14	63	(9)	13
	Grain	---	---	---	40(102)	(14)	74	---	---	---	---	---	---
	G. Manure	(41)	(6)	100	(91)	(14)	100	(57)	(9)	100	(63)	(9)	100
Profi pea	Forage	32	(3)	9	28	(5)	15	16	(3)	16	25	(4)	13
	Grain	---	---	---	41(30)	(5)	46	---	---	---	---	---	---
	G. Manure	(32)	(3)	100	(28)	(5)	100	(16)	(3)	100	(25)	(4)	100
Soybean	Forage	76	(13)	15	35	(18)	34	43	(13)	23	51	(15)	23
	Grain	65(48)	(13)	48	140(30)	(18)	26	76(40)	(13)	41	94(39)	(15)	37
	G. Manure	(76)	(13)	100	(35)	(18)	100	(43)	(13)	100	(51)	(15)	100

Number in parenthesis indicate the N remaining on or in the soil (N input). Numbers without parenthesis indicate the N output from the system.

proportion of N derived from biological fixation, and the timing of N release from residues and roots.

The results are coincident with those of Poss (2001), and Vigil and Nielsen (1998). In the Poss experiment total above-ground N uptake, averaged across sites and years was 70 kg N ha^{-1}. Legume root biomass in the 0-20 cm depth averaged 2080 kg ha^{-1} with a uptake of 18 kg N ha^{-1}. Vigil and Nielsen measured Austrian winter pea uptakes of 50 and 130 kg N ha^{-1} in 1994 and 1995, respectively.

An estimation of the N release for the subsequent wheat should consider the composition of residues and roots. According to Bruulsema and Christie (1987), the composition of legume plowdown may have as much influence on N release to the soil as the total N yield of the plowdown crop itself. Lignification of plant tissue may play a role in limiting the release of N from decomposing plant residue, and interactions between lignin concentration and the C:N ratio in controlling the decomposition rate of plant material have been reported. The release of legume N in Forage management is related to root composition. Soybean roots had higher N input than pea, but based on their higher C:N ratio and lignin concentration, less available N in the short time can be expected. The release of soybean N would probably be sequential: first from the nodules (C:N ratio of about 7), then from thin roots (C:N ratio of 25) and finally the higher amount from taproots, whose high C:N ratio (50) could produce temporary immobilization.

Considering the absolute N yields, neither the pea nor the soybean make an important contribution for the subsequent wheat crop. Estimates of legume residue N availability during the first subsequent cropping year reviewed by Hesterman et al. (1987) ranged from 10 to 34% of the N input. Any of these percentages applied to the average 15 kg N ha^{-1} in soybean roots make N input from legume Forage management negligible.

Under Grain management, the complement of the N input percentage presented in Table 3.1 represents the N harvest index (NHI): the percentage of total N that is exported with grain. Comparison between pea and soybean are possible only in 1999, a non-representative year. However, the calculated NHI values of 26, 54 and 76% for Austrian winter pea, Profi pea and soybean, respectively, show the important amount of N exported by the later crop. Studies cited by Bundy et al. (1993), comparing the amounts of symbiotically fixed N returned to the soil in soybean residues with the amounts of N removed in the harvested grain, indicate that soybean production results in a net removal of N from the soil.

Considering the average C:N ratio of soybean residues after grain harvest (about 39:1), N immobilization also may be expected, thus delaying the N availability for the wheat. Decreasing fall temperature and a dry soil in the upper layers are also factors to be considered in the low N contribution of soybean Grain treatments.

According to the original hypothesis, the Green Manure management was expected to provide the highest amount of available N for the system. On average the N input was 72, 29 and 66 kg N ha^{-1} (Table 3.1) for Austrian winter pea, Profi pea and soybean, respectively. These amounts are higher than Forage but similar to Grain management N level. Despite the fact that comparison was only possible in 1999, the N input from the two management levels did not differ among legumes. For soybean, the three year average showed 54 and 65 kg N ha^{-1} for Grain and Green Manure, respectively. The C:N ratio for their residues were however 39 and 12 respectively, indicating a potentially faster N release from Green Manure residues. Leaving the residues on the soil surface with no-till should further retard their decomposition in relation to plowing them into the soil. .

The four N fertilizer rates applied to the wheat after Austrian winter pea (Fig.2.12) were designed to evaluate the response of the wheat to increasing N rates after the legume. However, the higher yield of the wheat after Fallow in 1999, related to legume treatments, and the lack of significant differences in 2000 prevented any estimation of the N input from the legume. It suggested that: a) The N input from the legume was negligible. b) Or the N was not still available to the wheat. c) Or low water availability was so limiting that this factor was interfering with the N response.

The lower wheat yield after legumes in 1999, compared to wheat yield after Fallow, was related to lower soil water availability at wheat planting (Table 2.8), and at wheat tillering stage (Table 2.11). In 2000, soil water availability was not significantly different at wheat planting or at tillering stage (Tables 2.9 and 2.12). It is interesting to note that the tendency to increase wheat yield with N rate in 2000, appeared in the Fallow and Forage treatments, and not in Grain and Green Manure treatments. Fallow and Forage management had higher amounts of soil water at wheat planting and, theoretically, the lowest N input from previous management. Grain and Green Manure treatments were supposed to have higher N input and less soil water with a consequent lower potential for a response in wheat yield. These data could indicate that water availability, either for the residue decomposition or for crop growth, is one of the factors affecting the expression of the "legume N credits".

Mc Neil et al. (1997) pointed out that dry topsoil was a possible interference with N mineralization in dry years. Different experiments with N^{15} tracer cited by Nelson and King (1996), indicate that a major portion of the N in green manures is not available to crops grown immediatly following incorporation of the green manure. The results of this experiment, however, do not allow further conclusions and more information is needed to clarify this subject.

4. Soil water content

In agreement with reports of Farahani et al. (1998) and Peterson et al. (1996), the soil water change under Fallow (Fig.2.6) showed that no meaningful storage occurred during the later parts of summer fallow period. This supports the idea of finding a crop that could use the otherwise wasted water from rainfall that occurs during this period.

The legumes used rainfall and soil water, producing lower soil water contents than Fallow in parts or all the periods studied. Confirming the initial hypothesis, in all years the Forage peas, especially Austrian winter pea, used soil water and depressed the soil water content by their harvest, even in 1999 with higher than normal rainfall. Soybean did not depress soil water by their forage harvest date, except in the surface layer in 1998, indicating a higher rainfall than soil water utilization.

Under Forage management, the soil water content of Austrian winter pea and soybean did not differ from Fallow in 1998 and 1999. Soil water content in 2000 under Austrian winter pea was lower in the 30-120 cm layer, indicating the soil water use in the deeper layers and less profile recharge after harvest. Despite the fact that the soil after pea forage harvest has a higher ability to store rainfall than under Fallow (Poss, 2001), the rainfall during this period was not adequate to recharge the soil. Relative to Fallow, the soil water content at wheat planting in the Forage management level was 80, 102 and 75% for the pea, and 89, 95 and 86% for soybean in 1998, 1999 and 2000 respectively. This shows that the effect of growing soybean for forage, with a late utilization of the summer-fallow period, water is similar to that of Austrian winter pea, related to soil water depletion.

Grain legumes had less water than Fallow at wheat planting in 1998 and 2000. In 1999, with more rainfall, all grain treatments had lower soil water than Fallow, but the difference was significant only for Profi pea and Asgrow 2301 soybean. Under Grain management, the average soil water content at wheat planting was 79, 77 and 65% of the soil water content in Fallow in 1998, 1999 and 2000, respectively, for the pea, and 76, 78 and 71% for soybean in the same years. Again, the later growth period of soybean produced about the same effect as pea for grain on soil water content at wheat planting. However, when compared to the Forage management, the difference in soil water content was important every year related to soybean, but only in a wet summer for pea.

Green Manure management was expected to have greater advantages than was observed. Different problems related to the timing and effectiveness of the herbicide application to kill the crop in a timely manner, explains part of the results. Other facts to consider are: a) The need for a high cover crop to retain soil water against high evaporative conditions. This cover was probably adequate for the Austrian winter pea, but in soybean it was low and not enough for evaporation reduction. b) As expected, the rainfall that occurred after the killing of the crop was always higher for pea than for soybean, but even for pea it was only significant in 1999.

Soil water content at wheat planting after pea for Green Manure was 89, 90 and 79% of that of Fallow, and after soybean 81, 84 and 93% in 1998, 1999 and 2000, respectively. The better water storage after soybean in 2000 shows the importance of timing the herbicide application overall, however, the water storage efficiency of the Green Manure treatments was not much better than for legumes used for Forage.

5. Legume water use

Table 3.2 shows the water use of the legumes for the Forage and Green Manure management levels and the average water use of soybean for Grain. The water use efficiency (WUE), for the Forage management level and the average of Grain soybeans are also presented in this table.

The water use of the crop is an estimate of the evapotranspiration (Biederbeck and Bouman, 1994). The WUE is defined as the dry matter (forage or grain yield) produced divided by the growing season evapotranspiration or ET (Peterson et al. 1996). Since runoff and drainage often are not know, the ET is usually replaced by the soil water used plus the growing season precipitation (water use).

The water use values determined for the peas were comparable to those reported by Vigil and Nielsen (1998), for their legume termination dates of middle July in 1994 and 1995 in the Akron area. The Forage management had the lowest water use, while the Green Manure was higher and similar to the Grain management. The water use of the Green Manure treatments was equal to the water use of Forage treatments as was the WUE. In Table 3.2 the water use for this management level was estimated using a different period of time: from legume planting to wheat planting, in order to allow the potential advantage of the Green Manure to capture water to be expressed through more soil water at wheat planting. That was not the case, and the values were lower or about the same as the Forage treatments, showing that there was no real advantage to having more residue cover under the conditions of the experiment. Only soybean for Green Manure in 2000, with the best termination techniques, used amounts of water similar to Forage treatments. The water use of all legumes was closely related to the rainfall, increasing in 1999 with higher available water.

Soybean used more water than pea under Forage management in 1998, but equal or less in 1999 and 2000. Under Green Manure, soybean water use was generally lower than that of pea. Power (1991) found increasing water use for legumes with more precipitation received from planting to harvest. Zachariassen and Power (1991), in a greenhouse study, related the water use to the growth of the legumes, those with higher biomass production using more water. They found soybean used more water than

Table 3.2 – Legume water use and Water Use Efficiency for Austrian winter pea, Profi pea and soybean, as affected by residue management during 1998, 1999 and 2000.

		YEAR					
		1998		1999		2000	
Legume	Management	WU mm	WUE kg mm^{-1}	WU mm	WUE kg mm^{-1}	WU mm	WUE kg mm^{-1}
Austrian winter pea	Forage	135 c	9.3 a	394 a	7.2 a	270 bcd	6.3 ab
	Grain	—	—	455 b	1.8 d	—	—
	G.Manure	281 a	—	627 a	—	419 a	—
Profi pea	Forage	133 c	10.9 a	253 c	3.0 c	134 e	3.7 b
	Grain	—	—	442 b	2.3 c	—	—
	G.Manure	254 ab	—	585 a	—	307 b	—
Soybean 1	Forage	205 b	9.8 a	286 b	3.5 b	134 e	11.0a
	Grain	245 (*)	4.3 (*)	505 a	4.3 b	282 (*)	4.3 (*)
	G.Manure	238 ab	—	499 b	—	213 cd	—
Soybean 2	Forage	204 b	13.4 a	286 b	3.4 b	120 e	9.5 a
	Grain	245 ab	4.3 b	546 a	4.4 a	282 bc	4.3 b
	G.Manure	258 ab	—	544 b	—	215 d	—
F test		18.6	12.5	—	—	40.0	8.2
P-value		<0.0001	<0.0001	—	—	<0.0001	0.0008

Analysis of Variance 1999	Var = WU		Var. = WUE	
Source of variation	F test	P-value	F test	P-value
Legume	21.5	<0.0001	39.0	<0.0001
Management	484.6	<0.0001	902.2	<0.0001
Leg x Man	20.4	<0.0001	50.8	<0.0001

WU= water use, WUE= water use efficiency.
(*) Average value for the two soybean varieties.
For 1998 and 2000 data, in each column values with the same letter are not different at α=0.05 level. For 1999 data, in each Management level values with the same letter are not different at α=0.05 level.

fieldpea at 20 and 30°C. Different periods of utilization for both legumes in the present study, with variable growth and rainfall may explain the somewhat different performance observed.

The WUE was higher for the Forage than for the Grain treatments in most years. No differences among legumes were found in 1998. In 1999 Austrian winter pea had a higher WUE than soybean for Forage, and lower under Grain management, reflecting the differences in yield. In 2000, the WUE's of all legumes under Forage management were similar.

The WUE values for Forage averaged 7.6, 5.9 and 8.4 kg of forage per mm of water used for Austrian winter pea, Profi pea and soybean, respectively. These differences do not seem to have high agronomic relevance, at least comparing Austrian winter pea vs. soybean. Biederbeck and Bouman (1994) working at Swift Current (SK, Canada), reported a 7yr average WUE of 19.2 kg m^{-1} for feed peas. The higher value compared to the present results is probably related to a higher ET under Akron conditions.

Soybean for grain had a constant WUE of 4.3 kg of grain mm^{-1} of water use in all three years. When grain yield was achieved by the pea crops, the WUE was half of that of soybean, showing the lower potential of this crop. Considering the different production costs and values for forage and grain production, it does not seem valid to make a simple comparison between their WUE's.

6. Wheat production

Legume Grain management levels only affected wheat biomass at tillering, as related to soil water content at planting, in 1999. The higher initial soil water content for soybean compared to pea, and higher soil water content in the Forage management level indicated higher wheat biomass expectations for those treatments. The result was opposite, the wheat biomass at tillering was higher for after pea and for the Green Manure levels. The increase in soil water content in the upper soil layers between wheat planting and tillering (Table 2.11) seems to have provided enough water to overcame these initial differences. The higher residue cover in the Green Manure treatments may also have allowed more water capture in this case.

At wheat harvest, the deeper soil layers had been explored during the last stages of the crop, and despite high summer precipitation, wheat grain yield was highly related to differences in soil water content at planting. The yield after Profi pea for Green Manure (the highest soil water content after legumes) was the only treatment not significantly different than after Fallow. All other legume treatments were lower than Fallow and without significant differences among them. Responding to legume management, the wheat after legumes for Grain yielded less than after the other management levels, strongly corresponding to the initial soil water content.

On the average, wheat yield after pea and soybean were 68 and 75% of the yield after Fallow for the Forage management level, 54 and 45% for the Grain management, and 83 and 72% respectively for the Green Manure management. This ordering of yield reduction is in accordance with the order of soil water content at planting.

In 1999 the legume treatments did not differ in soil water content at wheat planting; Only Fallow had higher soil water than the lowest legume treatment, and most of the plots were close to field capacity in the upper soil layers (Table 2.9). This may have stimulated the initial wheat growth, helped by a mild winter.

At tillering, in spring 2000, the wheat had already used water from the deep layers of the soil (Table 2.12) and expressed small differences in initial soil water in terms of tillering stage biomass. Fallow and the Forage management level had similar biomass, both were higher than Green Manure or Grain management levels. At grain harvest, these differences were maintained or even enhanced by the dry season in the

Grain management treatments that had the lowest initial soil water content. Related to the wheat yield after Fallow, the yield after pea and soybean was 103 and 91% for Forage management, 73 and 60% for the Grain management, and 94 and 72% for the Green Manure management, respectively. Except for soybean for Grain that yielded less than expected, the other values are highly related to the soil water content at wheat planting.

These results agreed with the data of Poss (2001) who reported that rainfall during July, September and October, before and just after wheat planting, was more important to wheat yield than rainfall during the next spring-summer, when legumes preceded wheat instead of fallow.

Comparing the wheat yields after Austrian winter pea for Forage to yields after soybean for Forage or Grain was one of the objectives of this project. Austrian winter pea is considered the most adapted legume for the area, and the soybeans (especially for grain), represent a potentially more profitable alternative. Growing Austrian winter pea for forage decreased wheat yield 32% in 1999, and increased yield 3% in 2000. Vigil and Nielsen (1998) found smaller decreases after their earliest pea harvest dates at Akron, in 1995 (low precipitation) and 1996 (higher rainfall). The penalty in wheat grain yield for growing soybean for forage was 25% in 1999 and 9% in 2000, which is similar to Austrian winter pea.

When soybean was grown for grain, the wheat yield decrease related to wheat-fallow was large: 55 and 40% in 1999 and 2000, respectively. This wheat yield reduction was highly related to the soil water depletion caused by the soybean crop, using more water than the forage alternative.

Vigil and Nielsen (1998), working with pea, reported no differences in wheat yield depression due to the type (species) of legume used for forage. The present results confirm their finding even with soybean growing late into the summer. In addition, the data showed that the utilization of the legume (management for grain, forage or green manure) was more determinant of the yield depression than the species itself.

The N uptake data for wheat showed no special increment after the legumes. related to the fallow-wheat sequence, neither in grain nor in residues. This is in accordance with the lack of differences in wheat yield after legumes and different N rates in the wheat after Austrian winter pea data. It seems that no significant N input was made by the legumes for the subsequent wheat, even under Green Manure management.

Chapter 4

CONCLUSIONS

The legume dry matter production and its effect on subsequent wheat yield varied over the three years studied and was highly dependent on climatic conditions. The legume production represented two dry summers and one exceptionally wet season, that provided a good range of experimental conditions. The rainfall distribution for the spring-summer season differed from the long-term average with less precipitation than normal in the spring, two out of three years.

The wheat production occurred in two years with different combinations of climatic factors. The first year had a dry summer before wheat planting and was followed by an average winter and a wet spring-summer season. The second year had a wet summer period before wheat planting followed by dry winter and spring-summer periods. These characteristics should be considered when analyzing and using the conclusions of this study.

Averaged across the three years, the forage production of Austrian winter pea was 1873 kg ha^{-1}, compared to 1550 kg ha^{-1} for soybean and 831 kg ha^{-1} for Profi pea. The forage yield of soybean was equal or higher than for Profi pea, and only during an exceptionally wet spring-summer was the yield of Austrian winter pea higher than soybean.

Legume grain production was most risky for pea, with two years of no yield and only one year with yield of 832 and 1014 kg ha^{-1} for Austrian winter pea and Profi pea respectively. Soybean grain production was higher and more stable with an average grain yield of 1521 kg ha^{-1}.

The below-ground dry matter production over the three years was highest for soybean production; averaging 363, 187 and 1180 kg ha^{-1} for Austrian winter pea, Profi pea, and soybean, respectively, in the 0-36 cm depth. The N input from the legume roots averaged 9, 4 and 16 kg ha^{-1} for Austrian winter pea, Profi pea, and soybean, respectively. Most was in the top 0-18 cm of soil. The taproot system of the soybean provided higher root dry matter and N content. The different C:N ratios in the components of the soybean root system could affect the N release in time related to the peas, since nodules and thin roots decomposed first.

The total N returned to the soil the soil after termination of the Austrian winter pea, Profi pea and soybean was 9, 4, and 15 kg ha^{-1} when used for forage, and 72, 29, and 66 kg ha^{-1} when used for green manure. The estimation under grain management was complicated by the failures of pea in two years, but was similar to the green manure treatment.

The water use of the legumes was dependent on the precipitation during the growing period, the dry matter production and the utilization of the legume for forage, grain, or green manure. Average water use was 266, 173, and 206 mm for Austrian winter pea, Profi pea and soybean, respectively when used for forage production. When used for grain production, the average water use increased to 455, 442, and 526, respectively, during the wet year, the only one with grain production for pea. The three-year average water use of soybean for grain was 351 mm. The green manure utilization of the legumes had water use similar to forage. Water use of the legumes was closely related to the precipitation that occurred during their growing period, showing that they used all the water supplied from rainfall.

The WUE of the legumes for forage was 7.6, 5.9, and 8.4 kg forage mm^{-1} for Austrian winter pea, Profi pea, and soybean, respectively. The differences in WUE between forage legumes was non-significant in 1998, highest for Austrian winter pea in 1999 due to its high yield and lowest for Profi pea in 2000.

When managed for forage, legume water use resulted in soil water contents at wheat planting ranging from 80 to 102% of the water content under chemical fallow, with no differences among legumes. The differences related to fallow were only significant for pea in 2000. Legumes managed for grain production always reduced soil water content at wheat planting compared to fallow and other management. The effect was the same for all species and the soil water content ranged from 65 to 79% of the water content after fallow.

Soil water content after legumes for green manure was always lower than after fallow, with no differences among legumes. It ranged from 79 to 93% of the water content after fallow. Compared to fallow, the differences were generally non-significant, but the data showed that this technique did not improve water storage over the traditional fallow.

Wheat yield in 1999 after legumes was depressed related to yield after fallow. Growing legumes for forage or green manure instead of the traditional fallow produced a similar decrease ranging from 17 to 32%. Legumes for grain were more damaging to wheat yield, decreasing it from 46 to 55% compared to fallow.

In 2000, legumes for forage did not significantly depress the wheat yield compared to fallow. Yields after pea and soybean for forage were 103 and 91% of the yield after fallow. Legumes for grain decreased wheat yield from 27 to 40%, except wheat after Austrian winter pea for grain that yielded the same as after fallow. Legumes for green manure decreased wheat yield from 6 to 28% but only the highest was statistically significant.

No positive effects from potential N inputs from the legumes were observed in the subsequent wheat yield and N uptake. Water depletion by legumes had the major effect on wheat yield.

The hypothesis of the study was that the use of legumes to replace a part of the summer fallow, and with different utilization purposes, would produce effects on soil water at wheat planting and wheat yield, generating more interesting alternatives to replace summer fallow. This was partially confirmed by the results. There was no species effect on soil water and yield depression, but the utilization of the legumes did. Forage production, either with pea or soybean, had the least effect on wheat yield depression. Green manuring produced no evident benefits over fallow related to water storage, mainly due to management problems derived from the killing of crop and weeds and the lack of a proper amount of residues in some treatments. Grain production depressed wheat yield the most.

Two valid alternatives are evident from my results:

a) Forage production based on legumes is possible either with Austrian winter pea or soybean. The forage production of soybean may be improved if new forage varieties are tested. The forage yield and its effect on wheat yield depression is dependent upon climate conditions, but whatever the conditions were, there always will be some yield and the legume may be suppressed early if the conditions are really unfavorable for the subsequent wheat.

b) Grain production with reasonable risk seems to be possible only with soybean. Soybean yield can be lost, if conditions are not favorable, and the effect on wheat yield is high (close to 50% yield reduction in dry summers).

The selection of one of these alternatives depends on opportunity costs and farming strategies. The forage does not market readily and utilization must occur near the point of production, but some farms could benefit from it. The soybean grain production has a better market and price, but the whole soybean-wheat system gross income must be analyzed.

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