MANAGEMENT EFFECTS ON NITROGEN FIXATION AND WATER USE OF LUCERNE UNDER DRY SITE CONDITIONS

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Abstract

Biological nitrogen fixation is the main source of nitrogen in organic farming systems. There is little known about the impacts of cultivation techniques in pannonic regions on the capacity of biological nitrogen fixation (BNF) and the water use efficiency (ETC: evapotranspiration coefficient) of lucerne. From 1999 to 2001, pure lucerne crops and lucerne-grass mixtures were investigated with respect to the effect of the utilization system (harvested = forage production; mulched = green manure; pure lucerne crops versus lucerne-grass mixtures) on yield, BNF, soil N balance and the water use efficiency. The amount of total fixed N was 124-150 kg N ha^{-1} in 2000 and 178-197 kg N ha^{-1} in 2001. The proportion of N derived from the atmosphere (% N_{dfa}) ranged from 26 to 79%. When the proportion of grass yield in lucerne-grass mixtures was high enough (exceeding 20%), mixtures showed a higher water use efficiency than pure crops by using site resources more efficiently than the pure lucerne crops. The release of nitrogen from the legume mulch was inhibited due to unfavourable conditions for mineralization in both years. Therefore green manure legumes did not decrease nitrogen fixation and the proportion of nitrogen derived from the atmosphere. Nevertheless, mulching the legumes reduced the water consumption of the crops compared to the evapotranspiration of the forage legumes.

Introduction

Lucerne (*Medicago sativa* L.) cultivation, used as green manure or as forage legume, is important on organic arable farms under dry site conditions. The annual nitrogen fixation rates of lucerne range from 85 to 360 kg N ha^{-1} (Frame *et al.* 1998). Mulched lucerne crops have the ability to fix 210 kg symbiotic N ha^{-1} yr^{-1} (Loges *et al.* 1999). Environmental factors and management practices (e.g. cutting and removal versus cutting and mulching) will affect the amount of N fixed and also the fixation process. In a cutting regime, much of the fixed N is removed by harvest the forage legumes and the benefit to subsequent crops is reduced. On the contrary, with green manures where the cut material is returned to the soil as mulch, a proportion of the fixed N will be returned to the soil with the legume debris. Nitrogen fixation is likely to be affected by the additional mineral N released from the decomposing debris. Although the use of green manure legumes is the main agricultural practices on stockless farms in Eastern Austria, there is a surprising lack of information in the literature on the critical evaluation of this utilization system compared to forage production under dry, pannonic site conditions.

Methodology

Lucerne (cv. Orca) was sown as pure crop (seeding rate 30 kg ha^{-1}) and in mixture with grasses (seeding rate 24 kg ha^{-1} lucerne, 30 kg ha^{-1} grasses) in August 1999/2000 at Raasdorf (organically cultivated fields of the University of Natural Resources and Applied Life Sciences, Vienna). The climate in Marchfeld region is characterised by hot, dry summers with little dew, and cold winters with little snow. The mean annual temperature is 9.8°C, the average sum of precipitation 554 mm. The precipitation during the vegetation period in 2000 (501 mm) and 2001 (502 mm) was reduced compared to the long-term values. To estimate symbiotic N_2 fixation (according to McAuliffe *et al.* 1958), a low-level application of ^{15}N enriched fertilizer (1 kg potassium nitrate ha^{-1}, 10 at% ^{15}N) was conducted onto marked 2.25 m² subplots. ^{15}N marked plots with reference plants (grass-mixture: tall oat grass, red fescue, sheep´s fescue, meadow fescue) were established as well. The plants were harvested/mulched three times per year (May, July and

August). At seeding, before and after winter, and to all harvesting dates, soil samples for determining inorganic N (nitrate-N) and gravimetric soil water content were taken (3 layers: 0-30 cm, 30-60 cm, 60-90 cm). The field plots were laid out in a completely randomised block design with four variants (LCH: lucerne pure crops harvested, LGH: lucerne-grass mixture harvested, LCM: lucerne pure crops mulched, LGM: lucerne-grass mixture mulched) in four replicates. The shoot and stubble dry matter (DM) yield were determined by harvesting 2 x 1 m² of each plot and drying an aliquot at 105 °C until the weight remains constant. Part of the plant material was dried at 60 °C for 48 h, ground up to a fine powder, and analysed for N content and ^{15}N isotope ratios (ThermoQuest Finnigan DELTA^{plus}) in the laboratory of the University of Göttingen. The actual evapotranspiration of the crops was estimated by using the climatic water balance (Ehlers 1997).

Results and discussion

Soil nitrogen status

In spring 2000, a strong increase in nitrate-N under the legumes occurred (0-90 cm: 102 – 164 kg N ha^{-1}). Generally, we found no differences between the nitrate-N content under the pure crops and mixtures in both vegetation periods. Soil nitrate-N of the pure crops and mixtures did not differ at the second and third harvest 2000, because the grass yield proportion in the mixtures was below 20%. In spring 2001, the nitrate-N contents in soil were reduced compared to the values in spring 2000 (pure crops: 50 kg N ha^{-1}, lucerne-grass mixtures: 51 kg N ha^{-1}). The soil nitrate-N of green manure and forage legumes did not differ in both years. This suggested that the environmental conditions (especially precipitation) in spring were suboptimal for the mineralization of the legume mulch. At the second and third harvest 2001, where the precipitation was according to the long-term means, the soil nitrate-N under the mulched variants (second harvest: 39, third harvest: 24 kg N ha^{-1}) was twice as high as under the harvested variants (second harvest: 20, third harvest: 12 kg N ha^{-1}), but they did not differ significantly because of the high standard deviation.

Plant growth and yields

The lucerne/grass content of the harvested shoot matter in the mixtures varied strongly during both production years (grass proportion of the yield in 2000: 39% at the first harvest to 18% at the third harvest; 2001: 21% at the first harvest to 1.5% at the second and third harvest). Generally the legume/grass ratio in mixtures is dependent on temperature (Clark *et al.* 1995), the access to plant available nitrogen in soil as well as other nutrients (Marschner 1995) and water, thus legume-grass mixtures are intrinsincally unstable (Parsons *et al.* 1991). Furthermore more herbage is harvested from an erect cultivar at a fixed cutting height (5 cm above the crown), e.g. tall oat grass than from red fescue. The other grasses in the mixture (red, sheep´s and meadow fescue) obviously were not compatible with lucerne because the grasses did not grant the needed requirements (a sufficient development of shoot biomass after defoliation). The total shoot DM yield of the lucerne-grass mixtures (LGH, LGM) was significantly higher than that of the pure crops (LCH, LCM) in the year 2001 (Table 1) because of the high grass proportion of the yield at the first harvest. In general, mixtures profit by their varied intensity of using water and nutrients, where they utilise the site resources efficiently. The mulched variants reached more shoot and root yield at the first harvest 2001 than did the harvested crops, but as mulching started at the first harvest, this is caused by inhomogeneous soil properties on the trial site. Thus, the shoot, stubble and root DM yield was not affected by the utilization system in both years of investigation. This suggests that the shading effect of the legume mulch had no impact on the shoot yield of the green manure legumes.

Nitrogen fixation and proportion of nitrogen derived from atmosphere (N_{dfa})

The total nitrogen fixation (first to third harvest) reached from 124 (LG) to 150 (LC) kg N ha^{-1} in 2000 and from 178 (LC) to 197 (LG) kg N ha^{-1} in 2001. As a consequence to the soil nitrate-N contents, nitrogen fixation at the first harvest 2001 was twice as high as the BNF in 2000. In general, inorganic N is known to have negative effects on N_2 fixation in legumes (Vessey & Waterer 1992). Pure lucerne crops fixed a similar amount of N as did the lucerne-grass mixtures in both years (see Table 1). The proportion of nitrogen derived from the atmosphere (N_{dfa}) was significantly higher in the mixtures (57%) than in the pure crops (36%) at the third harvest 2000, where the grass proportion of the yield was 18% in the mixture. The high proportion of grasses in the mixture obviously increased N_{dfa} in the lucerne crops due to a reduced water consumption (see section "water use efficiency"). There were no significant differences in BNF and N_{dfa} between pure crops and mixtures in the year 2001 because the proportion of grass yield in the mixtures was too low to have an effect on these parameters.

Table 1: Shoot dry matter yield, nitrogen fixation and N_{dfa} (in shoots) of lucerne crops over a two year experimental period (2000 and 2001)

	Date	Shoot dry matter yield (t ha^{-1})				Nitrogen fixation (kg ha^{-1})				N_{dfa} (%)			
		LH	LM	LC	LG	LH	LM	LC	LG	LH	LM	LC	LG
00	10.5.	3.3[a]	3.2[a]	3.0[a]	3.7[a]	52[a]	61[a]	59[a]	48[a]	50[a]	48[a]	49[a]	53[a]
	5.7.	1.3[a]	1.0[a]	1.1[a]	1.3[a]	10[b]	23[a]	16[a]	10[a]	26[a]	79[a]	53[a]	26[a]
	4.9.	2.1[a]	2.2[a]	2.1[a]	2.2[a]	45[b]	126[a]	75[a]	66[a]	35[a]	37[a]	36[b]	57[a]
	Total	**6.6[a]**	**6.4[a]**	**6.2[a]**	**7.2[a]**								
01	14.5.	5.3[b]	9.1[a]	6.3[b]	8.1[a]	66[a]	110[a]	76[a]	100[a]	39[a]	59[a]	49[a]	67[a]
	26.6.	2.7[a]	2.3[a]	2.6[a]	2.4[a]	66[a]	42[b]	58[a]	50[a]	67[a]	55[a]	61[a]	58[a]
	10.8.	1.9[a]	2.1[a]	2.1[a]	1.9[a]	47[a]	44[a]	44[a]	47[a]	44[a]	19[a]	32[a]	40[a]
	Total	**9.9[b]**	**13.4[a]**	**11.0[b]**	**12.3[a]**								

LH = mean of LCH + LGH, LM = mean of LCM + LGM, LC = mean of LCH + LCM, LG = mean of LGH + LGM; shoot nitrogen fixation at first / second harvest, total plant nitrogen fixation at third harvest;
[abc:] Means within one row and date followed by the same letter are not significantly different ($P < 0.05$)

In the present investigation the climatic conditions were suboptimal for a fast mineralization of the legume mulch (little precipitation in both investigation years). As a result, BNF of green manures was not reduced. Under the dry conditions in the Marchfeld region, Farthofer (2004) noticed that mulching fodder legumes did not increase the N mineralization potential and inorganic nitrogen content in soil under the first and second subsequent crop compared to harvesting. BNF of the green manure variants (LM) was increased compared to the harvested variants (LH) at the second and third harvest in 2000. This significant difference could be a methodical problem (see Pietsch 2004), but is not substantiated by higher soil nitrate-N or herbage yields of the green manures compared to the harvested crops. The nitrogen fixation of the mulched variants was significantly lower than that of the harvested variants in the following production year (e. g. second harvest in 2001: harvested variants 66 kg N ha^{-1}, mulched variants 42 kg N ha^{-1}). Loges *et al.* (2002) also found higher BNF rates in harvested lucerne-grass mixtures compared to mulched lucerne grass-mixtures. The yield independent N_{dfa} value was not influenced by the utilization system in both production years.

Water use efficiency

The average evapotranspiration coefficient (ETC) for summer 2000 (March until August) of LGH (361 L kg^{-1}) was significantly lower than the ETC of variant LCH (539 L kg^{-1}). This difference was mainly a result of the first harvest, where the grass proportion in the mixture was high (39%). Grasses have thinner and more branched roots, rooting the soil intensely and have therefore advantages in competition with legumes regarding to the nutrient and water absorption. The high water consumption of lucerne is explained by the restricted mechanism of the stomata (Haynes 1980). In the year 2001, lucerne pure crops evaporated the same amount of water as did the lucerne-grass mixtures, because the proportion of grass yield in the mixtures was very low.

Table 2: Evapotranspiration and evapotranspiration coefficient (ETC) of lucerne variants over a two year experimental period from March to August

Date of sampling		Evapotranspiration (mm)		ETC (L kg^{-1})	
Year /	Month	LH	LM	LH	LM
2000	03 - 08	285[a]	232[b]	450[a]	379[a]
2001	03 - 08	309[a]	306[a]	312[a]	235[b]

LH = mean of LCH + LGH, LM = mean of LCM + LGM; [abc:] Means within one row followed by the same letter are not significantly different ($P < 0.05$)

The evapotranspiration of the green manure variants was lower than that of the harvested crops in the year 2000 (Table 2), because the legume mulch covered the soil and thus reduced the evaporation. Frye *et al.* (1988) confirmed also that mulching with plant material reduced the evaporation and water loss to the atmosphere by shading the soil surface.

Conclusions

From this study it can be concluded that yield and nitrogen fixation of lucerne in the pannonic region was strongly depended on water supply and mineral nitrogen in soil. When the proportion of grass yield in lucerne-grass mixtures was high enough (exceeding 20 %), mixtures showed a higher water use efficiency than pure crops by using site resources more efficiently than pure crops. The grass species in the mixture were little resistant against the several cuts under the dry climatic conditions. Therefore more appropriate grass species should be used. The release of nitrogen from the legume mulch was inhibited due to unfavourable conditions for mineralization in both years. Therefore green manure legumes neither increased soil nitrogen contents nor decreased the proportion of nitrogen derived from the atmosphere. Nevertheless, mulching legumes reduced the water consumption of the crops and lead to a higher water use efficiency compared to the harvested legumes.

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