International Journal of Agricultural Science Research Vol. 3(6), pp. 099-111, June 2014
Available online at http://academeresearchjournals.org/journal/ijasr
ISSN 2327-3321 ©2014 Academe Research Journals

Full Length Research Paper

Identification of traits for lucerne ideotype under organic farming conditions

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Accepted 26 June, 2014

Information on yield and root traits of lucerne (*Medicago sativa* L.) varieties used under organic farming conditions is currently lacking. Field experiments were conducted for two consecutive years (2007-2008) to generate information on the said traits and identify the traits that a lucerne ideotype shall possess under organic farming conditions. Experiments were conducted under irrigated and rainfed conditions near Vienna, Austria. Results revealed that differences among varieties were non-significant for the above- and below-ground biomass. Varieties tended to perform better under irrigated conditions as compared with rainfed conditions in both years of study mainly because of the effect of supplemental irrigation. Sitel was found to be the superior variety in high shoot and root dry matter yield and yield consistency and can be a suitable choice for use as parent in breeding lucerne for organic farming conditions. Desirable traits identified for lucerne improvement were shoot yield, relative water content and root biomass. Root traits shall be assigned high priority in selecting parents for breeding lucerne for organic farming conditions due to the dominant role of roots in water and nutrient uptake and source of residues left over in soil for turn over and long term improvement of soil health.

Key words: Crop improvement, *Medicago sativa*, relative water content, root biomass, yield.

INTRODUCTION

Organic farming systems (OFS) rely on legume nitrogen fixation as a main nitrogen (N) source, crop residues and nutrients mobilized from the soil reservoirs, as use of chemical fertilizers is restricted. Under OFS, the choice of crop varieties is constrained by lack of varieties developed specifically for OFS. These systems usually use varieties originally developed for conventional farming systems. Because the area under certified organic farming is gradually increasing in Europe and the rest of the world, additional crops and varieties must be included in OFS (Willer et al., 2009). This will increase diversification and lead to sustainability of these systems (Ronchi and Nordone, 2003). Legumes are important crops in OFS because of their nitrogen (N) fixation capability and nutrient recycling (Howieson et al., 2000). Among legumes, lucerne (*Medicago sative* L.) is the key crop that ensures sustainability of OFS (Shen et al., 2009) because of its contribution towards N-fixation. The plant can survive long periods of drought (White, 1967; Volaire, 2008) and can improve soil drainage (Shen et al., 2009).

Lucerne breeding for OFS under arid and semi-arid conditions shall focus on developing varieties that can

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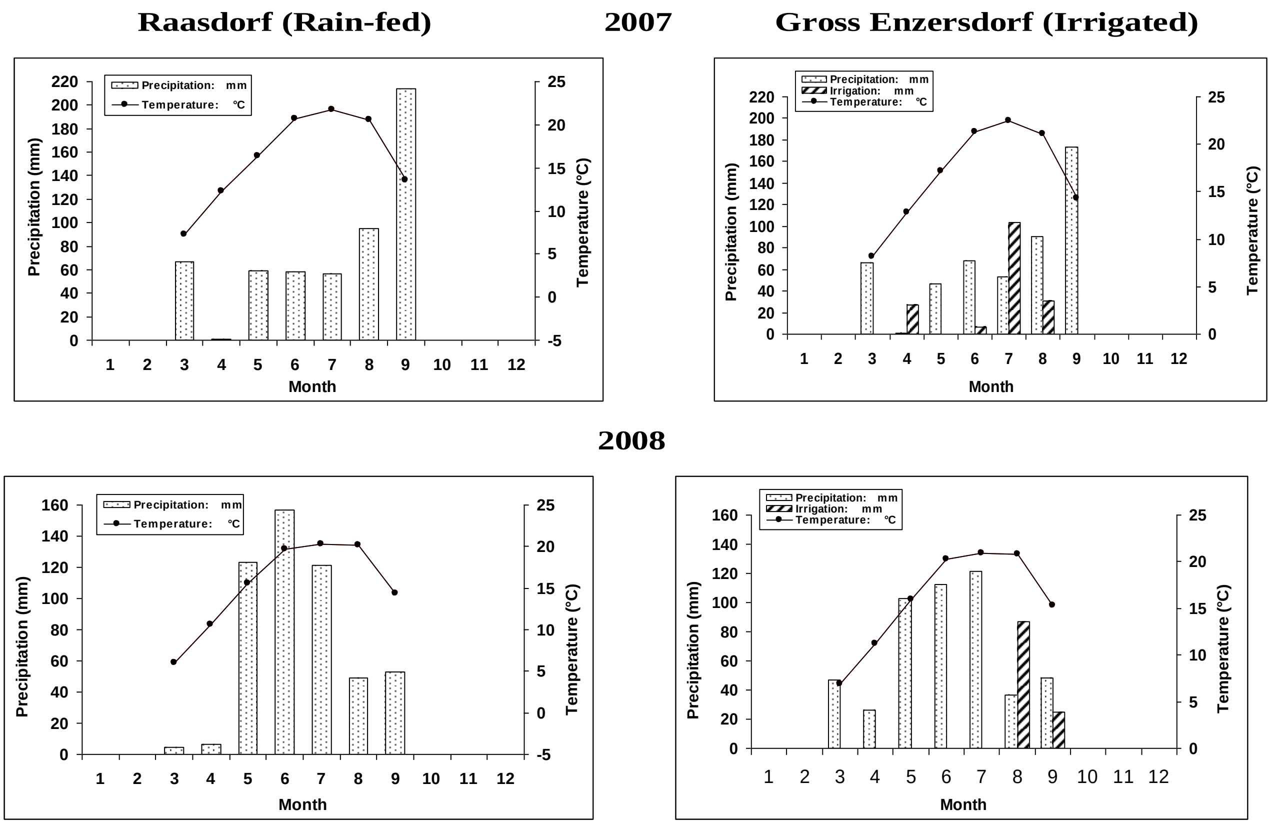

Figure 1. Monthly precipitation, average temperature and applied irrigation water from March to September (2007-2008).

perform better under the conditions of both low soil fertility and limited water availability. Selection of high yielding parents possessing desirable morphological, physiological and root traits is the first step in this direction. Morphological traits may be of less significance relative to physiological traits and root traits. Root traits assume additional importance as plants become totally dependent on available soil nutrient reserves exploited by roots as external input of chemical fertilizers is not allowed under organic farming conditions. Under semi-arid conditions, irrigation water for supplemental irrigation is usually not available so the varieties shall be efficient in water use (in our area of study, that is, Marchfeld, irrigation is available, but for forage legumes it is not economical).

Roots play a dominant role in varietal performance both under organic farming and conventional farming conditions on account of their key role in water and nutrient uptake. Root characteristics attain high priority under organic farming conditions because of the dominant role of roots in carbon sequestration, but studies on root traits of lucerne are lacking in literature. Identification of desirable traits and their use in breeding lucerne for OFS is an exciting area of research that has received less attention in recent past. Keeping in view the importance of lucerne, a study was designed to identify desirable traits (with special emphasis on root traits) that an ideal genotype shall possess for high performance under organic farming conditions.

MATERIALS AND METHODS

Experimental set up

The present study comprised two different experiments, namely irrigated and rainfed, planted at Groß Enzersdorf (48º12' N, 16º33' E) and Raasdorf (48º15' N, 16º37' E), respectively. Both of these sites have organically managed fields and belong to the research station of University of Natural Resources and Life Sciences (BOKU), Vienna, Austria. Raasdorf is about 7 km away from Groß Enzersdorf: the climatic variation between the two experimental sites is not significant. The climate is characterized by hot, dry summers with little dew, and cold winters with little snow. The mean daily temperature is 9.8°C and the mean annual precipitation is 520 mm (based on data from 1971-2000). Soils at the two sites are silty loam with an organic carbon content of 0.4-1.5% and a bulk density of 1.4-1.6 g cm^{-3} in 0-90 cm of soil profile. The amount of precipitation, mean temperature and applied irrigation water from March to September in 2007-2008 are shown in Figure 1. Soil physical properties

Table 1. Physical properties of experimental sites.

Depth (cm)	Bulk density (g cm^{-3})	Sand (%)	Silt (%)	Clay (%)	Textural class	Soil water content(m^3 m^{-3}) at field capacity(-0.33 bars)	Soil water content(m^3 m^{-3}) at permanent wilting point(-15 bars)	Available soil water(m^3 m^{-3})
Gross-Enzersdorf								
15-20	1.62	20	57	23	Silty loam	0.310	0.195	0.115
50-55	1.57	33	50	17	Loam	0.320	0.144	0.176
80-85	1.58	27	62	11	Silty loam	0.283	0.083	0.200
90-120	-	5	70	25	Silty loam	-	-	-
Raasdorf								
15-20	1.37	17	60	23	Silty loam	0.287	0.159	0.128
50-55	1.40	14	69	17	Silty loam	0.266	0.103	0.163
80-85	1.44	20	70	10	Silty loam	0.302	0.064	0.238
90-120	-	41	52	7	Silty loam	-	-	-

are presented in Table 1.

Each experiment was laid out in a randomized complete-block design with two replicates. Three lucerne varieties namely Niva, Mohajeran and Sitel were used. Sowing of both experiments was done manually in 2006 using a seed rate of 25 kg ha^{-1}. Row-to-row distance was 12.5 cm. Each plot having a single lucerne variety was 1.5 m and 2 m long for irrigated and rainfed site, respectively and 1.5 m wide in both sites. First year was regarded as establishment year and next two years (2007-2008) were regarded as experimental years. Drip irrigation system was used for the irrigation treatment. Irrigation was applied based on regular monitoring of soil water content (SWC) using FDR (Frequency Domain Reflectometry, ML2×, UMS GmbH, München, Germany) probes. The FDR probes were installed in each replicate at depths of 10, 40, 80 and 120 cm. Irrigation was started at 50% depletion of soil available water (SAW) content (SAW = water content difference between field capacity (FC) and permanent wilting point (PWP), based on FDR probe in 10-15 cm soil depth). The amount of applied irrigation water was calculated for 0-30 cm depth based on soil moisture content up to field capacity.

Soil and root sampling

Each year at the start of vegetation period and after each harvest, soil samples for the determination of inorganic N content were collected from both experimental sites using a mechanical auger from depths of up to 90 cm with every 30 cm increment. Soil samples for the determination of texture, bulk (dry) density and retention curves were collected from both experimental sites at the end of vegetation period in 2008. Two representative replicates were selected for sampling from each experimental site on the basis of variation in soil texture determined by finger testing method. One soil sample was collected from each replicate from depths of 15-20, 50-55 and 80-85 cm.

Root samples were taken at final harvest in each year from both sites. In 2007, cylindrical augers (diameter of 1-3 cm) were used to take root samples till the depth of 90 cm at 30 cm intervals. One sample was taken on the row and two samples were taken between the rows from each lucerne plot, which were mixed and washed. During the first harvest in 2008, two samples were taken on the row and two between the rows from each lucerne plot using cylindrical augers; samples were washed separately. Root sampling at final harvest in 2008 involved the use of 7 cm diameter auger. Sampling was done till the depth of 60 cm at 10 cm intervals. One sample was taken on the row and one between the rows from each lucerne plot: samples were washed separately. Root biomass for first harvest of year 2008 was calculated regarding the percentage of area present on and between the rows. Based on these results of root biomass, a correction factor was devised to correct root biomass for year 2007, where percentage of roots present in and between the rows was not taken into account.

Assessment of above-ground plant parameters

Data on above-ground biomass and associated characters namely: shoot height, shoot number, leaf to stem ratio, leaf area index (LAI), relative water content (RWC) and chlorophyll content were recorded at three main harvests from both sites to calculate yearly mean and total yearly shoot dry matter yield. Plots were hand-clipped at 30-40% of flowering using garden scissors to a 5-cm stubble height. An area of 0.5 m^2 was harvested from each plot at each harvest to determine shoot biomass. Stubble biomass was determined only on final harvest in each year. Shoot and stubble dry matter yield were determined by oven-drying the sub-sample at 60°C for 48 h. Shoot dry matter (SDM) yield data at final harvest includes value of stubble dry matter yield also.

Number of stems per m^2 and leaf to stem ratio were determined in a sub-sample of 0.25 m^2 taken from each lucerne plot. Shoot number was calculated on sub-sample of 0.25 m^2 and converted to shoot number per m^2. Shoot height was measured manually on standing crops in the field using wooden meter rod. Leaf area index was measured using LAI-2000 Plant Canopy Analyzer (LI-COR, Lincoln, NE), before each harvest and yearly means were calculated. Chlorophyll contents (mg m^{-2} leaves) were measured using a portable chlorophyll meter, Yara N-tester (Yara international ASA, Norway) at main harvests. Chlorophyll content (mg m^{-2} leaves) was measured from 30 fully expanded leaves in the upper 15 cm of plant canopy. Fully expanded leaves from top 15 cm were used to determine RWC following Gonzalez (2003):

$$RWC = \{(\text{fresh weight - dry weight})/(\text{saturated weight - dry weight})\} \times 100$$

Assessment of below-ground plant parameters

Soil samples were washed to collect roots using a hydro pneumatic elutriation system (Gillison's Variety Fabrication Inc., USA) through a sieve with a mesh of 760 µm. Roots were dried at 60°C for 48 h for determination of root dry matter yield. Each year, samples from final harvests of both sites were scanned using a scanner (Epson Expression/STD 1600 extra optimized for root analyses by Regent Instrument, Inc.) following Himmelbauer et al. (2004). On these samples, root characters, including root length, root surface area (RSA), root volume (RV) and average diameter (AD) were determined using a commercial software package WinRHIZO 4.1 (Regent Instruments 2000). The entire amount of roots available from each sampling depth in each replicate was scanned. Root length density (RLD) was determined by dividing the root lengths by volume of respective soil sample.

Assessment of evapotranspiration and water use efficiency

Soil water content was measured using FDR probes and Sentek Diviner at irrigated and rainfed sites, respectively. The FDR (Frequency Domain Reflectometry, ML2×, UMS GmbH, München, Germany) probes were installed at depths of 10, 40, 80 and 120 cm, whereas SENTEK Diviner 2000 (Sentek Sensor Technologies, Australia) probes were installed at a depth of 120 cm. Soil water content was measured using manual data loggers for both types of probes at weekly to fortnightly intervals.

Actual evapotranspiration (ETa) of the lucerne varieties was calculated for each harvest according to the climatic water balance (Ehlers and Goss, 2003):

$$N + B = T + E + A + S + \Delta R$$

where N, B, T, E, A, S and ΔR are precipitation, irrigation, transpiration, evaporation, surface runoff, leaching and change in the water content of the soil profile (0-120 cm), respectively. Precipitation and meteorological data were obtained from a nearby weather station. The total amount of applied water was determined for the rainfed site based on total precipitation and for irrigated site based on sum of the total precipitation and applied irrigation water during the vegetation period for respective harvests in each year. Surface run-off was ignored, because the experimental fields were flat (A = 0). It was assumed that no significant amount of leaching occurred (S = 0) beyond the root zone during vegetation period based on prevailing precipitation trends and water content data. The following simplified equation was used to calculate ETa:

$$ETa = T + E = N + B - \Delta R$$

Water use efficiency of productivity (WUE_P) was calculated using shoot dry matter production (SDM) from each harvest for both sites, separately. Respective water consumption (ETa) values were derived from water balance calculations:

$$WUE_P = SDM / ETa\ [\text{kg DM m}^{-3}\ H_2O]$$

Soil analysis

Inorganic soil N content (nitrate only) was determined in the laboratory of Division of Organic Farming using N-min analysis method. Ammonium content was not determined as sites had negligible amounts of ammonium on account of pH values being 7.6 (Pietsch et al., 2007). Soil organic carbon (C) contents were determined using the following relationship:

$$\text{Soil organic carbon (\%)} = \text{Total C} - \text{Carbonate C}$$

Total C contents of soil were determined by dry combustion and infra-red detection of CO_2 using C-N 2000 Elemental Analyser (LECO). Carbonate-C content was determined following the method developed by Institute of Soil Research, University of Natural Resources and Life Sciences, Vienna, Austria.

Particle size analyses are based on determination of percentage of sand (0.063-2 mm), silt (0.063-0.002) and clay (<0.002) in a soil sample. Particle size analyses involved dry sieving to separate particles > 2 mm, wet

Table 2. Significance levels for fixed factors and their interactions for biomass and its components of three lucerne varieties at the two sites.

Parameter/Harvest	Effect	2007				2008			
		1	2	3	Yearly average	1	2	3	Yearly average
Shoot dry matter yield (tones ha^{-1}) §	Site	*	*	*	*	+	ns	*	*
	Varieties	*	ns	ns	*	ns	*	ns	ns
	Site*Var	*	ns	ns	*	ns	ns	ns	ns
Shoot height (cm)	Site	*	*	*	*	ns	*	*	*
	Varieties	ns	ns	*	*	ns	*	ns	ns
	Site*Var	ns	ns	+	*	ns	ns	ns	ns
Shoot number m^{-2}	Site	ns	*	ns	*	+	ns	-	ns
	Varieties	*	*	*	*	ns	ns	-	ns
	Site*Var	*	*	*	+	ns	ns	-	ns
Leaf area index	Site	*	*	*	*	ns	*	*	*
	Varieties	ns	ns	ns	ns	*	ns	ns	ns
	Site*Var	ns	ns	ns	+	*	ns	ns	ns
Leaf to stem ratio	Site	ns	*	+	*	ns	*	-	*
	Varieties	*	ns	ns	*	+	+	-	*
	Site*Var	ns	*	ns	+	+	ns	-	ns
Relative water content (%)	Site	*	ns	-	+	-	-	ns	ns
	Varieties	ns	ns	-	ns	-	-	ns	ns
	Site*Var	ns	ns	-	ns	-	-	ns	ns
Chlorophyll content (mg m^{-2} leaves)	Site	ns	ns	-	ns	ns	*	ns	ns
	Varieties	+	ns	-	ns	ns	ns	+	+
	Site*Var	ns	ns	-	+	ns	ns	ns	ns

Note: ns, non-significant; *, significant at 5% level of probability; +, significant at 10% level of probability; §, total yearly shoot DM yield instead of yearly average.

sieving (for < 2 mm) and pipette approach (for < 0.063 mm). Based on relative proportion of sand, silt and clay, textural classes were determined following American textural triangle adopted from American Soil Survey Manual (Soil Survey Staff, 1951).

Bulk density was determined using the following relation proposed by Blake and Hartge (1986):

$$\text{Bulk density (g cm}^{-3}\text{)} = \text{mass of oven-dried soil sample (g) / volume of core (cm}^{3}\text{)}$$

Retention characteristics were measured for each site by pressure plate analysis (Dane and Hopmans, 2002).

Statistical analysis

Data from each parameter were analyzed separately for each year, and data on WUE_P were analyzed for each harvest separately. Data from three varieties in both sites were analyzed using general linear model of statistical software SPSS (version 15), where varieties and sites were considered as fixed factors and replicates were considered as random factors. All data sets were treated according to a randomized complete block design. Mean comparison was done using Student Newman Keuls (SNK) test at 5% level of probability.

RESULTS

Above-ground biomass and its components

Based on yearly means in 2007, a significant interaction between sites and varieties was found for all parameters related to above-ground biomass and its components except for RWC. Based on yearly means in 2008, a non-significant interaction between sites and varieties was found for all parameter related to above-ground biomass and its components (Table 2).

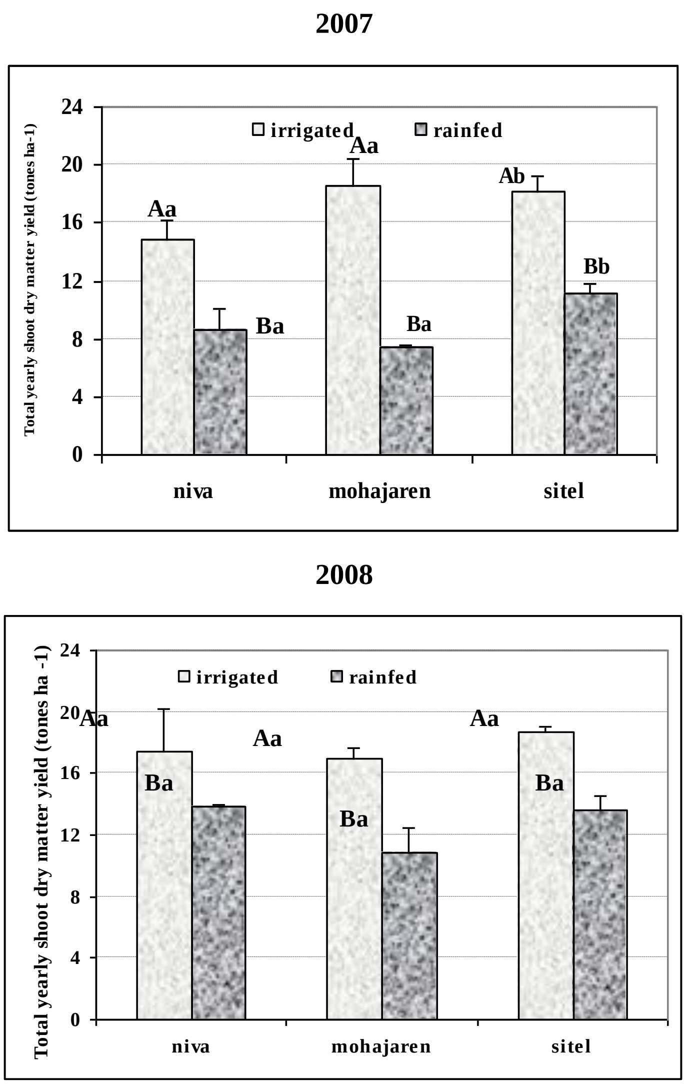

Figure 2. Total yearly shoot dry matter yield of lucerne varieties under irrigated and rain-fed conditions (2007-2008).
Error bars indicate one standard deviation. Significant differences among sites and varieties are represented by different capital and small alphabets, respectively.

Shoot dry matter yield (SDMY)

Total yearly shoot dry matter yield varied from 8.3 to 18.6 tons ha^{-1}. The two sites differed significantly in producing total yearly SDMY. The SDMY of lucerne varieties was higher under irrigated site as compared with the rainfed site in both years. On the overall basis, Sitel was found to be superior in producing SDMY under both sites, followed by Niva and Mohajaren (Figure 2).

Shoot height (SH)

Based on yearly means, shoot height varied from 46 to 101 cm. Based on yearly means, SH was higher in irrigated site (71-101 cm) as compared with rainfed site (46-84 cm). Based on yearly means, Mohajaren had higher SH compared to Sitel and Niva at both sites.

Shoot number (SN) (m^{-2})

Based on yearly means, shoot number was in the range of 762-1306 m^{-2}. Lucerne varieties differed significantly (P< 0.05) in their SN only in 2007 where Mohajaren had the highest shoot number (1061 m^{-2}), followed by Sitel (965) and Niva (773).

Leaf area index

The LAI varied from 1.5 to 4.6. LAI was higher under irrigated site as compared with the rainfed site (Figure 3)

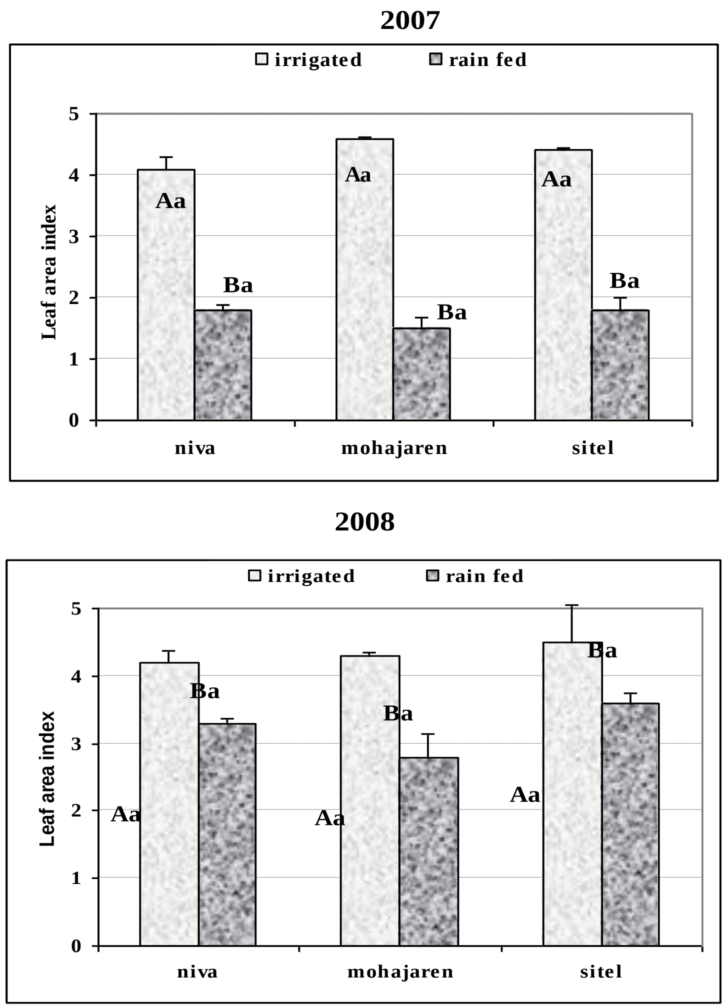

Figure 3. Leaf area index of lucerne varieties under irrigated and rain-fed conditions.
Error bars indicate one standard deviation. Significant differences among sites and varieties are represented by different capital and small alphabets, respectively.

because of optimal amount of irrigation water available at the irrigated site. Based on yearly means, it can be concluded that Mohajaren>Sitel>Niva in irrigated site, whereas for rainfed site, Sitel>Niva>Mohajaren.

Leaf to stem ratio

Based on yearly means, leaf to stem ratio varied from 0.5 to 1. In both years, varieties had relatively higher leaf to stem ratio at the rainfed site when compared with irrigated site. Based on yearly means, leaf to stem ratio of varieties varied from 0.67 to 1.02 at the rainfed site as compared with 0.54 to 0.93 at the irrigated site.

Relative water content

Based on yearly means, varieties had relatively higher RWC under rainfed conditions (76-93%) than under irrigated conditions (75-90%). Differences among varieties were non-significant for this trait in both years.

Chlorophyll content (mg m^{-2} leaves)

Chlorophyll content varied from 641 to 752 (mg m^{-2} leaves). Differences between the two sites were non-significant for this trait. Overall, Sitel had the highest chlorophyll content in both sites and years.

A comprehensive summary of findings from the two sites for SDMY and its components based on yearly means (2007-2008) is shown in Table 2.

Root biomass and associated parameters

Root biomass

Root biomass in the 0-60 cm of soil profile ranged from 8252 to 16140 kg ha^{-1} at the time of final harvest in 2008.

Table 3. Significance levels for fixed factors and their interactions for root biomass of three lucerne varieties at the two sites.

Effect/Harvest	2007		2008	
	1	3	1	3
Site	ns	ns	ns	ns
Variety	ns	ns	ns	ns
Depth	*	*	*	*
Site* Var	ns	ns	ns	*
Site*Depth	ns	ns	ns	ns
Var*Depth	ns	ns	ns	*
Site*Var*Depth	ns	ns	ns	*

Note: ns, non-significant; *, significant at 5% level of probability.

Interactions among sites and depths were non-significant in both years (Table 3). Differences among sites and varieties were non-significant for root biomass, but differences between sampling depths were significant ($P< 0.05$) in both years.

Based on results of 2008 in irrigated site, Sitel had the highest biomass (16140 kg ha^{-1}), followed by Mohajaren (8881 kg ha^{-1}) and Niva (8252 kg ha^{-1}), whereas in rainfed site, Niva produced the highest biomass (11136 kg ha^{-1}), followed by Mohajaren (11101 kg ha^{-1}) and Sitel (8658 kg ha^{-1}). Results on root biomass in every 30 cm profile in both sites at the time of termination of experiments in 2008 are presented in Figure 4.

Root length density (RLD)

The RLD describes root length per unit soil volume. In the present study, interactions among sites, varieties and depths, showed that varieties and depths were non-significant in both years. Interactions between sites and depths and among varieties and depths were significant ($P< 0.05$) in 2007 but non-significant in 2008 (Table 4). The RLD usually tended to increase with depth in both sites in the first year of study. Higher values of RLD were observed for the rainfed site (0.5-1.6 cm cm^{-3}) as compared with the irrigated site (0.4-1.2 cm cm^{-3}). In 2007, there were significant differences ($P< 0.10$) between sites and among varieties for RLD. The RLD was also significantly different ($P< 0.05$) among sampling depths. In 2008, differences between sites and among depths were significant ($P< 0.05$), but differences among lucerne varieties were non-significant. The RLD ranged from 1.6 to 7.1 cm cm^{-3} and 1.0 to 4.9 cm cm^{-3} at the rainfed and irrigated site, respectively. Varieties in rainfed site had relatively higher RLD in both years. The RLD of lucerne varieties for every 10 cm profile for both sites is shown in Figure 5. In 2008, varieties usually had higher RLD in upper soil layers as compared with the lower soil layers. These findings are in line with those of Zahid (2009).

Root surface area (RSA)

Measurements of RSA are important as root biomass data do not provide information on active root surface area because of bias by large and inactive roots (Box and Ramseur, 1993). The RSA influences the kinetics of water and nutrient uptake (Smika and Klute, 1982). The RSA ranged from 15 to 459 cm^2. In the present study, interactions between sites and varieties, sites and depths, and varieties and depths were found to be significant for 2007 and non-significant for 2008. Interaction among sites, varieties and depths was non-significant in both years. There were non-significant differences ($P< 0.05$) between sites for RSA in both years. The RSA also differed significantly ($P< 0.05$) among sampling depths. In 2007, RSA varied from 15 to 82 cm^2 in the irrigated site, whereas RSA values for the rainfed site varied from 31 to 72 cm^2 in the 0-90 cm soil profile. In 2008, RSA values for irrigated site in the 0-60 cm soil profile were in the range of 56-377 cm^2 whereas RSA for rainfed site varied from 119 to 459 cm^2. Differences among varieties were significant ($P< 0.05$) in 2007 and non-significant in 2008. This may be attributed to the fact that in 2007, roots were still actively growing but by 2008, roots might have reached their maximum RSA resulting in no significant differences.

Varieties in the rainfed site had usually higher RSA as compared with the irrigated site in both years. These results match with the results of RLD. In 2007, RSA was higher in lower soil depths but in 2008, trend changed slightly and upper soil layers generally had higher RSA. Based on total RSA (0-60 cm), at the final harvest in 2008, Niva produced the highest RSA followed by Sitel and Mohajaren in the irrigated site whereas Mohajaren produced the highest RSA followed by Sitel and Niva in the rainfed site.

Root volume

Interactions between sites and varieties were non-significant in both years. Interactions between/among sites and depths, varieties and depths and site, varieties and depths were found to be significant in both years. Sites did not have a significant effect on root volume in both years but lucerne varieties differed significantly ($P< 0.05$) in their RV in 2007 but did not differ significantly in 2008. In 2007, Niva had the maximum RV of 3.18 cm^3 followed by Mohajaren (2.5 cm^3) and Sitel (1.63 cm^3) in the irrigated site. In the rainfed site, varieties had the same ranking as at the irrigated site with Niva having the maximum RV (2.45 cm^3) followed by Mohajaren (2.34 cm^3) and Sitel (1.76 cm^3). There were significant differences ($P< 0.05$) in RV at different depths in both years of study. Higher proportions of RV were concentrated in upper 30 cm of soil profile for both sites. Significant differences among RV in 2007 and non-significant differences in 2008 corresponded to results of RSA.

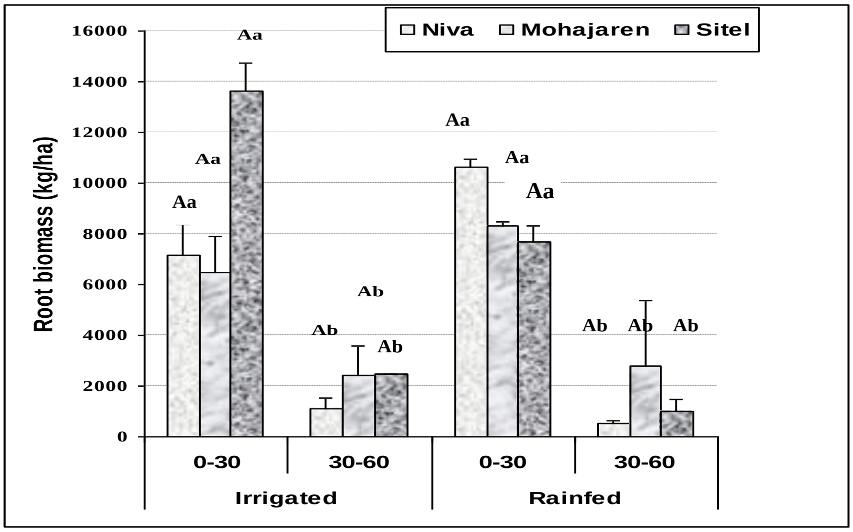

Figure 4. Root biomass of lucerne varieties at final harvest (2008) under irrigated and rain-fed conditions.
Error bars indicate one standard deviation. Significant differences among varieties and depths are represented by different capital and small letters, respectively.

Table 4. Significance levels for fixed factors and their interactions for root characteristics of three lucerne varieties at the two sites.

Effect/Year	2007				2008			
	Root length density	Root surface area	Root volume	Average diameter	Root length density	Root surface area	Root volume	Average diameter
Site	+	+	ns	ns	*	+	ns	ns
Variety	+	*	*	+	ns	ns	ns	ns
Depth	*	*	*	*	*	*	*	ns
Site* Var	ns	+	ns	ns	ns	ns	ns	ns
Site*Depth	*	*	*	ns	ns	ns	*	ns
Var*Depth	*	*	*	*	ns	ns	*	ns
Site*Var*Depth	ns	ns	*	+	ns	ns	+	ns

Note: ns, non-significant; *, significant at 5% level of probability; +, significant at 10% level of probability.

Average diameter (AD)

Root diameter influences net ion influx into roots (Barber, 1995). Roots with smaller diameters usually exhibit better nutrient and water uptake capacity than those with larger diameter. Fine roots are assumed to account for the majority of the uptake surface of the plant (Eissenstat and Caldwell, 1988). Interactions between sites and varieties and between sites and depths were found to be non-significant in both years. Interactions between varieties and depths and among sites, varieties and depths were found to be significant and non-significant in 2007 and 2008, respectively.

There were non-significant differences in AD at both sites in both years and these results are acceptable as fineness of roots is usually not influenced by site. Lucerne varieties did not differ significantly (P< 0.05) in their AD in both years. In the irrigated site in 2007, AD of Niva, Mohajaren and Sitel was 0.28 to 0.59 mm, 0.27 to 0.33 mm and 0.28 to 0.34 mm in the 0-90 cm soil profile, respectively. In the rainfed-site, AD of Niva, Mohajaren and Sitel was 0.27 to 0.48 mm, 0.25 to 0.41 mm and 0.27 to 0.45 mm, respectively. Significant differences (P< 0.05) were detected for depths in 2007, but differences were non-significant among depths in 2008. This can be attributed to the continual growth of roots in 2007 and probable cessation of growth in 2008. The AD varied from 0.24 to 0.35 mm for irrigated site and 0.21 to 0.49 mm in 0-60 cm soil profile at the time of final harvest in 2008.

Water use efficiency (WUEp)

The WUEp varied from 0.8 to 4.6 kg m^{-3} in the present

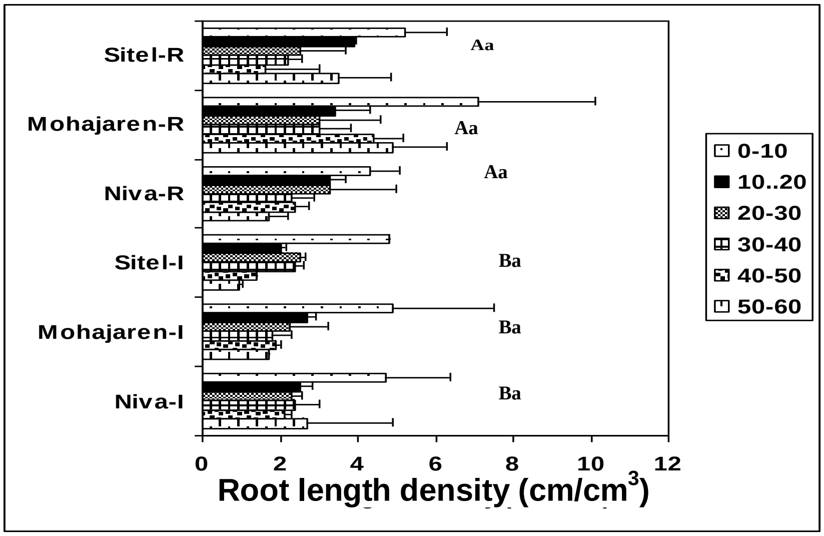

Figure 5. Root length density (cm cm^{-3}) of lucerne varieties under rain-fed and irrigated conditions (2008).
Error bars indicate one standard deviation. Significant differences among sites and varieties are represented by different capital and small letters, respectively.

Table 5. Significance levels for fixed factors and their interactions for actual evapotranspiration of three lucern varieties at the two sites.

Effect/Harvest	2007		2008		
	2	3	1	2	3
Site	*	ns	*	*	*
Varieties	ns	ns	ns	ns	*
Site* Var	ns	ns	ns	ns	*

Note: ns, non-significant; *, significant at 5% level of probability.

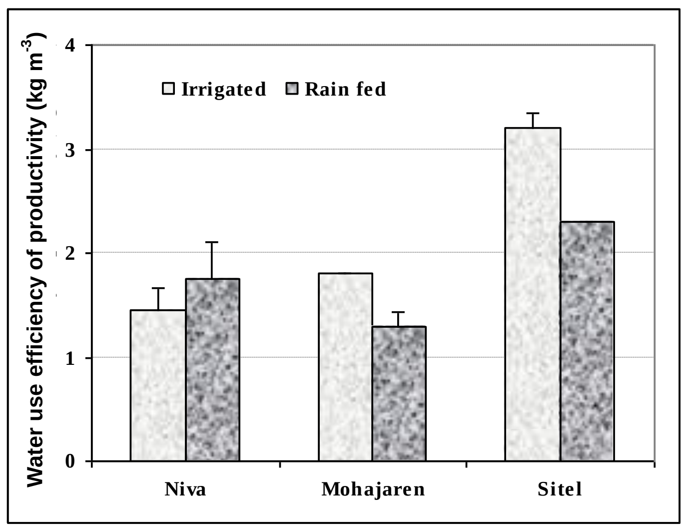

Figure 6. Water use efficiency of productivity of lucerne varieties at final harvest in 2008.
Error bars indicate one standard deviation.

study. Interaction between varieties and site was significant at first and final harvests in 2008 (Table 5). At the first harvest from irrigated site in 2008, Sitel had the highest WUE (4.6kg m^{-3}) followed by Niva (3.65 kg m^{-3}) and Mohajaren (3.6 kg m^{-3}) whereas from the rainfed site, Niva had the highest WUE (2.25 kg m^{-3}) followed by Mohajaren (2.1 kg m^{-3}) and Sitel (2 kg m^{-3}). Significant differences ($P< 0.05$) were observed between sites for their WUEp at all harvests except the final harvest in 2008. Irrigated site usually had higher values of WUEp (1.4-4.6 kg m^{-3}) as compared with the rainfed site (0.8-2.3 kg m^{-3}) at all harvest in both years. These differences were expected because of higher yields in irrigated site. Lucerne reportedly produces higher yields and WUE under light and frequent irrigations (Saeed and El-Nadi, 1997). Differences among varieties were found to be non-significant at all harvests in both years. Overall, Sitel had relatively higher WUEp under both irrigated and rainfed conditions. The WUEp of lucerne varieties at final harvest in 2008 is presented in Figure 6. Differences between sites for WUEp seem largely attributable to differences in irrigation and water holding capacity of the sites. Higher values of WUEp in the irrigated site as compared with rainfed site are associated with higher SDMY.

Inorganic nitrogen content

The inorganic nitrogen content in the soil profile (0-90 cm) varied from 1 to 135 kg ha^{-1} and 0 to 25 kg ha^{-1} for irrigated and rainfed site, respectively. Soils in irrigated site had relatively higher inorganic N content as compared with soils in rainfed site only during major part of vegetation period in 2007. During 2008, inorganic nitrogen content of the two sites was almost similar as nitrogen was used by lucerne plants in vegetation period of 2007. These variations in inorganic soil nitrogen of two experimental sites can have implications for the performance of lucerne varieties as nitrogen plays a key role in crop growth, yield and WUE (Latiri-Souki et al., 1998). Organic C contents at both sites were maximum up to 1.5% in 0-90 cm of soil profile.

DISCUSSION

Overall lucerne varieties performed better under irrigated conditions than under rainfed conditions for yield and yield components. These differences can partly be attributed to relatively lower organic carbon contents in 30-90 cm soil profile under rainfed site that led to lower water holding capacity. Soils in the rainfed site were slightly better relative to soil available water as revealed by retention curves data (Table 1) but this did not seem to have much effect on yield performance probably because this was superseded by the effect of irrigation and better stand establishment and high vigor of irrigated crop. It is emphasized that optimal amount of water was available for maintaining plant growth under irrigated site throughout the vegetation period through supplemental irrigation. No supplemental irrigation was provided to rainfed site thereby creating a water deficit at this site. This water deficit led to a reduction in SDMY for lucerne as reported in earlier studies (Carter and Sheaffer, 1983). Crop establishment under irrigated site was relatively better than under rainfed site (visual observations) during the early two years of experiment (2006-2007) and this might have led to superior performance of lucerne in 2008 under irrigated conditions even when lower amounts of supplemental irrigation were applied to crop. We must emphasize the role of crown reserves in perennials like lucerne in the regeneration of growth after winter period. Dense crop stands and high vigor of irrigated lucerne helped it to perform better in 2008 even when lower amounts of supplemental irrigation were applied. In the rainfed site, crop stand and establishment were poor and crop with low vigor was unable to perform better throughout the experimental period (2007-2008). Higher values of leaf to stem ratio were usually observed under rainfed site as compared with irrigated site. This may be attributable to the fact that water deficit caused a cessation of stem growth while leaf growth continued thereby leading to a higher leaf to stem ratio. Increase in leaf to stem ratio under water deficit conditions has also been reported in earlier studies (Carter and Sheaffer, 1983; Halim et al., 1989).

Lucerne ideotype for organic farming conditions shall have high vigor, high yield and yield stability. Sitel appeared to be a suitable variety in this regard as it consistently performed better under both irrigated and rainfed conditions in both years of experimentation.

Non-significant differences among varieties for physiological parameters (RWC and chlorophyll content) in the present study explained that narrow genetic diversity existed among studied varieties. That is why they did not produce significantly different results for drought sensitive parameters. Lucerne ideotype for organic farming conditions shall be able to maintain higher RWC to withstand periods of drought. Chlorophyll content shall ideally be higher in varieties to be used or bred for organic farming conditions. This will help in converting solar radiation efficiently under the conditions of low N levels in soils under organic farming conditions.

Rainfed site had relatively higher root biomass as compared with irrigated site. Under water-limited conditions, roots tend to grow more in search of water. Contrasting and inconclusive results have been reported by earlier workers (Jodar-Karimi et al., 1983; Luo et al., 1995) on lucerne roots because of difficulties associated with traditional methods of studying roots in the field as these methods require more labor, time and equipment. Root studies are associated with high variability coupled with the variability in the environment and the age of plant being studied (Sheaffer et al., 1988).

Contrasting results have also been reported earlier for lucerne root studies (Jodar-Karimi et al., 1983; Luo et al., 1995). During 2007, possible causes of higher RLD in lower soil layers can be colliding of root branches in middle to lower soil layers (30-90 cm) because of relatively narrow row spacing, mixing of on the row and between the row samples, small number of replications and small diameter of augers used in root sampling. Heterogeneity in root distribution studies even with higher number of replicates is well known besides this root distribution itself is highly variable (Bengough et al., 2006). In 2008, varieties had higher RLD in upper soil layer (0-30 cm) as compared with lower soil layer (30-60 cm). These findings coincide with those of Zahid (2009). Results of RLD in second year of studies seemed to be more reliable because of the use of larger diameter auger (7 cm) and washing and analysis of on the row and between the row samples separately.

Root traits shall be the focal point for organic lucerne breeding. Genotypes possessing higher root biomass will contribute in the shape of organic residues left over in the soil for turn over. Root length density is the key trait as genotypes having higher values of RLD in upper part of soil profile with a deep tap root will be ideal. Higher RLD in upper part of soil profile means that contact area of roots with soil is high that will ensure higher absorption of nutrients as most of the soil nutrients are present in upper part of soil profile because of the fact that organic residues are mixed in soil in top 30 cm of soil. A deep tap root will enable the plants to extract water from deep layers of soil provided enough amount of water remains available in the soil during periods of water scarcity and there is no mechanical impedance to root development. Root diameter is another valuable trait and usually fine roots are more active in absorption of water and nutrients. Fine roots are also subject to rapid decay. Lucerne ideotype shall have relatively higher proportion of fine roots.

Under non-stressed irrigated conditions of the present study, Sitel was the leading variety in producing highest RDMY and can be a suitable choice as a parent for further improvement of lucerne varieties under organic farming conditions.

Conclusion

The present study aimed to identify varieties for OFS and traits that a variety shall possess to perform better under organic farming conditions. Sitel was found to be the most superior variety on account of its high shoot and root yield and yield consistency over both years of study. We propose to use Sitel as a variety as well as a parent in lucerne breeding programs for organic farming conditions in Austria. Roots shall be assigned high priority when selecting parents for use in breeding as use of chemical fertilizers is restricted in organic farming so nutrient recycling through residues left over from previous crops and roots attain high weightage under these conditions.

Dominant role of roots as residues left over in the soil after harvesting the crop necessitate developing varieties that possess high root yields. Breeders shall additionally screen for high root length density and rooting depth. Varieties having higher root length density in upper part of soil profile help the plants to absorb nutrients that are usually concentrated in top 30 cm soil profile. Varieties having high rooting depth enable the plants to survive long periods of drought in areas where water remains available in deep soil layers during summer. Identification of desirable traits and their use in the improvement of lucerne for organic farming conditions is an objective worth pursuing. Our study was a starting point in this direction but we propose further studies on diversified commercial genotypes from conventional farming systems so as to identify more parents having high yield and diversity in root traits for further exploitation in lucerne breeding for organic farming conditions.

ACKNOWLEDGEMENTS

The authors highly acknowledge Higher Education Commission, Government of Pakistan, for providing scholarship for undertaking this research and all the departments at BOKU for permitting to use the laboratory facilities.

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