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Adaptability of Lucerne, Cocksfoot and Tall Fescue Genotypes in Mediterranean Environment under Different Application of Water Supply

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ABSTRACT

Dry matter of perennial species in Mediterranean environments depends on agronomic management, weather conditions and edaphic habitus of growing plants. Experiments on genotypes of perennial legume (lucerne, *Medicago sativa* L.; and graminaceous, cocksfoot, *Dactylis glomerata* L. and tall fescue, *Festuca arundinacea* Schreb.) were established, from 1996 to 2001, in an environment (Foggia, southern Italy) with a typical Mediterranean climate. The genotypes of three species were evaluated under rainfed and irrigated conditions. Irrigation integrated 80% of water lost by evapotranspiration from the lucerne, cocksfoot and tall fescue genotypes. Forage defoliation of the genotypes was performed when 45-50% of stems in the plot had flowered. The experimental design was a combined split-plot in time and factorial design replicated four times. The parameters assessed in the study were dry matter (t ha^{-1}), stem height (cm), stems m^{-2} and leaf: stem ratio (%). Irrigation treatment, in comparison to rainfed, doubled the time of agronomic utilization of the crops (3 vs. 6 years) and increased the dry matter yield by 24.35 t ha^{-1} in lucerne, 11.71 t ha^{-1} in cocksfoot and 14.67 t ha^{-1} in tall fescue. The adaptability of genotypes within crops to growing conditions were determined by cluster analysis which identified genotypes with superior fitness and adaptability to weather resources. Tall fescue was the crop with highest percentage of genotypes in all traits of the selected homogeneous group. Furthermore, because the genotypes Coussouls, Equipe, Lodi and Romagnola in lucerne; Cesarina and breeding population in cocksfoot; Maris Kasba and Tanit in tall fescue are included in more than one selected cluster group, they are endowed by physiological mechanisms able to better adapt and perform in weather conditions of Mediterranean climate.

Keywords: biomass harvests, dry matter, irrigation, perennial forage crops, performance

INTRODUCTION

Knowledge of seasonal distribution of herbage growth is essential for planning dairy management and for optimizing seasonal distribution of herbage productivity for feeding livestock. Weather conditions occurring during the vegetative cycle of perennial legumes and grasses affect plant development and most physiological activities of plant growth and the quality of the forage (Russell *et al*. 1978; Fairbourn 1982; Carter and Sheaffer 1983; Peterson *et al*. 1992; Martiniello *et al*. 2000; Pimentel 2004; Fageria *et al*. 2006).

The effect of harsh weather conditions on forage production in perennial crops may be reduced with adequate experimental treatments able to limit the impact of environments on crop growing. Thus, knowledge on edaphic behaviours of perennial crops and genotypes' adaptability to cope with the weather Mediterranean climate are essential to better exploit the weather resources of environments.

Irrigation during harsh months (June-October), in Mediterranean environments, is the agronomic practice able to satisfy the water demand of crops, to promote increase of the agronomic utilization of the meadow and to stabilize forage production across years (Martiniello 1999; Doll 2002; Tawaha *et al*. 2005). Available studies on annual forage crops underlined the impact of harvest management and irrigation on plant development and herbage production (Martiniello and Ciola 1995; Martiniello 1999; Pimentel *et al*. 2004). However, reports on the effect of irrigation on herbage production and environmental adaptability of perennial forage crops and their impact on plant regrowth after harvest in Mediterranean environments are limited (Martiniello 1998; Deng 2006). Studies conducted on direct field comparisons of ontogeny and adaptability of perennial crop varieties better adapted to cope with varied weather conditions were able to garner information of the successful management of crops in environments with agronomic interest (Ervin 1995; Murphy *et al*. 1997; Pimentel 2004; Tawaha *et al*. 2005; Fageria *et al*. 2006). Therefore, agronomic field evaluations of released perennial cultivars for forage production provided an opportunity to identify suitable genotypes able to exploit environmental resources and to increase biomass production (Denison *et al*. 1980; Pimentel 2004; Tawaha *et al*. 2005). The evaluation and the determination of the effect of irrigation treatments on dry matter production and yield components allowed useful information on crop management to be used to better exploit yield potentiality of the available genotypes.

This study investigates the adaptability and performance of the most diffused genotypes of perennial grasses – cocksfoot (*Dactylis glomerata* L.) and tall fescue (*Festuca arundinacea* Schreb.) – and legume – lucerne (*Medicago sativa* L.) – used for agronomic utilization in Mediterranean environments. The objectives of the experiments were to evaluate the effect of the available weather resources of the Mediterranean environment on the performance and adaptability of lucerne, cocksfoot and tall fescue genotypes under rainfed and irrigated growing conditions. The comparisons between the effect of irrigation vs. rainfed condition were made on first and second harvests of the two growing conditions in 1996, 1997 and 1998, while a comparison of the effect of water supply on plant development was made among six harvests per year on genotypes of lucerne and on three harvests on genotypes of cocksfoot and tall fescue

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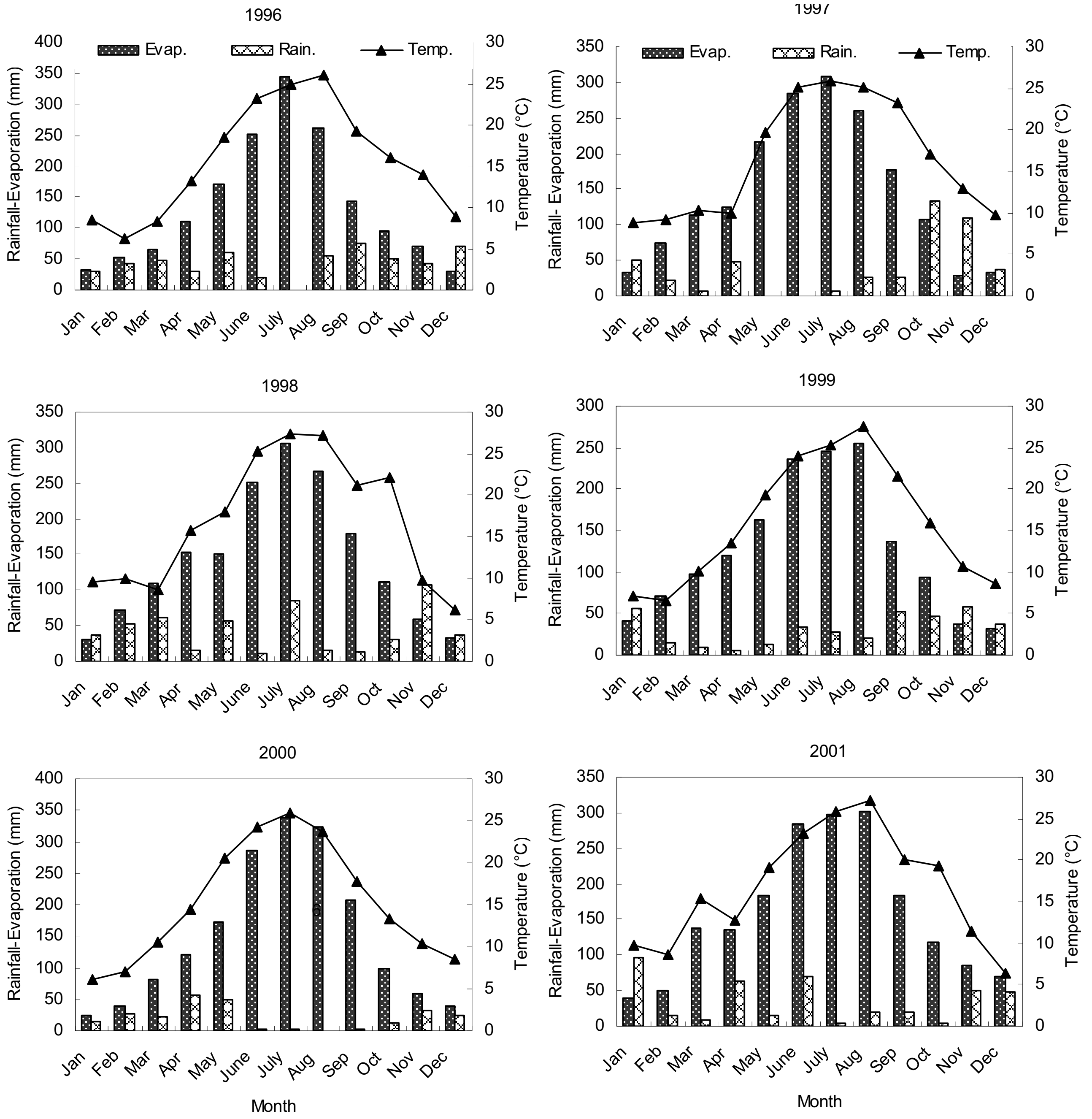

Fig. 1 Temperature, rainfall and evapotranspiration diagram in the year of the experiment of the site studied. Climatic observation represents a mean of the values of the month in the years of evaluation.

during six years of field crop evaluations (1996 through 2001).

MATERIALS AND METHODS

The experiment was carried out on the farm of the CRA Institute of Forage Crops (Southern Italy, a typical Mediterranean environment) located in Foggia (15° 13′ E, 41° 18′ N and 76 m above sea level) on a Chromic Vertisoil (FAO-ISRIC-ISSS, 1998) with the following characteristics: coarse sand (2-0.2 mm) 360 g kg^{-1}; fine sand (0.2-0.02 mm) 110 g kg^{-1}; silt (0.02-0.002 mm) 430 g kg^{-1}; clay (<0.002 mm) g kg^{-1}; pH (water) 8.2; cation exchange capacity 456 cmole g^{-1}; total ($CaCO_3$) 89 g kg^{-1}; total nitrogen (Kjeldal) 1.3 g kg^{-1}; organic matter (Walkey-Black) 23 g kg^{-1}; available phosphorous 17 mg kg^{-1} and exchangeable potassium 920 mg kg^{-1}. During field evaluation, the mean annual rainfall, the daily mean temperature, the ETo (measured from Class A water pan) and de Martonne aridity index was 446 mm, 15.9°C, 1680 mm and 15, respectively (**Fig. 1**). The highest annual rainfall occurred from October to June (80% of annual total rain); the amount of rainfall felt, in the remaining months, may be considered erratic (Martiniello 2001). Information regarding the origin of genotypes and breeding populations of lucerne, cocksfoot and tall fescue used in the experiment, their flowering time and year of release are reported in **Table 1**.

In the second week of October, 1995 seed of 10 lucerne, 8 cocksfoot and 7 tall fescue genotypes were sown by drill seeders in a 10 m^2 plot at the seed rate of 40 kg ha^{-1} for lucerne, and 30 kg ha^{-1} for both cocksfoot and tall fescue. The plot was composed of 14 rows, 5 m long and spaced 0.14 m apart. The seedbed was made by disrupting soil with a mouldboard ploughed 35 cm deep at the beginning of September. Prior to seeding, nitrogen fertilizer (36 kg ha^{-1} as ammonia) and phosphorous (92 kg ha^{-1}as P_2O_5) were applied to the grass crops during seedbed preparation by smoothing the soil with a field cultivator and tine arrow. In the following year 100 kg ha^{-1} nitrogen fertilizer (as ammonium nitrate) was applied to tall fescue and cocksfoot in two runs at the rate of 50 kg ha^{-1} each (February and October) while phosphorous (as superphosphate) was applied to all species in February at the rate of 90 kg ha^{-1} of P_2O_5.

The experimental treatments included either irrigated or non-irrigated (referred to throughout paper as rainfed) treatments.

Table 1 List of crop species, origin, flowering data of the first harvest and year of genotype release.

Name of genotypes	Genotype description	Origin	Flowering data [a]	Year of release
Lucerne				
Cinna	Cultivar	France	150	1978
Coussouls	“	“	150	1970
Equipe	“	Italy	148	1995
Europe	“	“	148	1987
Iside	“	“	147	1990
Lodi	“	“	152	1970
Luzelle	“	France	152	1972
Magalì	“	USA	150	1972
Romagnola	Ecotype	Italy	150	1972
Lucene BP*	Breeding population	“		2001
Cocksfoot				
Bepro	Cultivar	Poland	144	1987
Cambria	“	England	147	1995
Cesarina	“	Italy	144	1997
Lodola	“	Italy	144	1995
Luna Raskilde	“	France	144	1980
Lutezia	“	“	144	1991
Padania	“	Italy	140	1995
Cocksfoot BP*	Breeding population	“	144	2001
Tall fescue				
Lince	Cultivar	Italy	137	1991
Magno	“	“	136	1977
Maris Kasba	“	England	143	1990
Penna	“	Italy	136	2001
Sibilla	“	“	139	2001
Tanit	“	“	139	2000
Tall fescue BP*	Breeding population	“	136	2001

* BP= Breeding population

[a] = Days from 1st January

Table 3 Number of watering, total water applied (mm ha^{-1}) and aridity index in 6 years of experiments (Y1 = 1996, Y2 = 1997, Y3 = 1998, Y4 = 1999, Y5 = 2000 and Y6 = 2001).

Description of treatment	Year					
	Y1	Y2	Y3	Y4	Y5	Y6
Number of applications [a]	6	8	8	7	9	7
Total water applied by irrigation [b]	480	640	640	560	720	560
De Martonne aridity index [c]	20	17	20	15	11	17
WUE [d]						
Lucerne	170	216	215	211	278	285
Cocksfoot	280	344	416	418	722	654
Tall fescue	257	327	305	305	443	378

[a] = number of irrigations per year

[b] = mm of water supplied per ha

[c] = pure number

[d] = Litres of H_2O evapotranspired per kg of dry matter yield

Irrigation was applied to plots when evapotranspiration (ETo), computed using FAO's cultural species coefficient according to Doorenbos and Pruitt (1977), reached 80 mm. The number and time of harvests made on the crops, across the years of evaluation, are reported in **Table 2**. Plots were watered through a horizontal bar (16 m long, 1.23 m above the surface of the soil) moved by a hydraulic system and with a nozzle pressure of 0.19 MPa. According to Stanhill (1987), the environmental impact on the crop was evaluated by determining the water use efficiency (WUE). WUE was determined as the amount of water available for transpiration (computed from guidelines proposed by Doorenbos and Pruitt (1977), required per dry matter production unit (WUE, kg ha^{-1} mm^{-1}). The number of irrigations, the amount of water applied, the aridity index (De Martonne 1926) of the environment and the WUE of the crops in the years of evaluation are shown in **Table 3**.

Lucerne, cocksfoot and tall fescue were harvested when 45-50% of tillers in the plots had flowered (**Table 3**). Traits measured were: herbage biomass (t ha^{-1}); plant height (cm, mean of six values taken from ground level to main apex); stem density (stems m^{-2}, assessed from two samples picked from two linear 0.5 m rows), leaf stem proportion (ratio between weight of leaves and whole stem expressed as a %). The dry matter yield (t ha^{-1}) was assessed on the harvested biomass of the whole plot, adjusted for moisture concentration determined on samples of about 500 g of fresh biomass. The samples were dried at 60°C in an oven with force ventilation until the weight of biomass remained constant and then dry matter was determined.

The experimental design used was a mixed model based on a split-plot in time and factorial design with four replications. Statistical analysis was conducted separately for each forage species by using PROC ANOVA of SAS system procedure (SAS Institute 1997). The data of experiments recorded across the period of evaluation were analysed with three different statistical methodologies. In the models year, irrigation and genotype were considered as fixed effects and harvest and replication as random effects (Steel and Torrie 1980).

Determination of irrigated vs. rainfed effect

The data of the first and second harvest (HI-R 1 and HI-R 2 under both rainfed and irrigation treatment) of the years 1996 = Y1, 1997 = Y2 and 1998 = Y3 of both irrigated and rainfed treatments were analysed according to a split-plot in time model with irrigation in the main plot, and genotypes of crop species and harvest in the sub-plot (**Table 2**). The means of year and harvest between irrigated vs. rainfed treatment were compared by Duncan's Multiple Range test (DMRT) while comparison within years and harvests of irrigated and those of rainfed by the Least Significant Difference (LSD). DMRT and the LSD test were both determined utilizing the appropriate error terms of split-plot statistical analysis (Steel and Torrie 1980).

Effect of irrigation on agronomic period of growth

The effect of irrigation within years and harvests during the agronomic period of crop utilization was assessed by factorial analysis with years, harvest and genotypes as first, second and third factors, respectively. In the factorial analysis the levels of year were 6 for all crops; those of harvest were 6 for lucerne and 3 for both cocksfoot and tall fescue; and those of genotypes were 10, 8 and 7 for lucerne, cocksfoot and tall fescue, respectively. Year and harvest means comparison were made according to the LSD test and computed using the appropriate error term of the ANOVA factorial analyses (Steel and Torrie 1980).

Adaptability and performance of genotypes

The adaptability of traits to the environmental conditions in each species were evaluated by analyzing the data of the harvested

Table 2 Number and months of harvests made in the years of evaluation under irrigate and rainfed condition of perennial crops evaluated in the experiments.

Irrigated Code number harvest year^{-1}	Irrigated condition Month of harvests made 1996 through 2001			Irrigated - Rainfed Code number harvest year^{-1}	Rainfed condition Month of harvests made 1996 through 1998		
	Lucerne	Cocksfoot	Tall fescue		Lucerne	Cocksfoot	Tall fescue
HI 1	May	May	May	HI-R 1	May	May	May
HI 2	June	June	June	HI-R 2	June	June	June
HI 3	July	October	October				
HI 4	August						
HI 5	September						
HI 6	October						

genotypes of irrigated and rainfed treatments, according to Scott and Knott's (1974) cluster procedures as described by Gate and Bilbro (1978). The observations of each parameter of irrigated and rainfed conditions were grouped according to the null distribution of λ. This statistic, as defined by Edwards and Cavalli-Sforza (1965), when applied to univariate means of data, is a random variable with a Student's distribution. Computation of λ provided partitions of the mean varieties of parameter in groups, so that the inter- and intra-group showed a maximum and minimum sum square variability, respectively. By performing the likelihood ratio test (Gates and Bilbro 1978), on data of harvests across the years of evaluation for both irrigated and rainfed treatment, two cluster groups were identified. The means within each cluster group had minimum mean square interactions and were not statistically significant while the means between clusters were significant at $P \geq 0.05$ level of probability.

RESULTS

Irrigation vs. rainfed effect on forage crop growth

Analysis of variance of irrigated and rainfed observations related to the first two harvests of the first three years (1996 = Y1, 1997 = Y2, 1998 = Y3) in lucerne, cocksfoot and tall fescue crops, revealed significant effects of main factors of the experiments (**Table 4**). In all forage crops irrigation and harvests were the agronomic factors which produced most significant differences in all measured traits (**Table 4**). The higher effect of irrigation variability observed in lucerne for dry matter, stem height and leaf stem ratio was due to higher susceptibility – ascribed to the higher adaptability to growing in spring-summer – of the crop to irrigation treatment than cocksfoot and tall fescue. The higher effect of harvest in cocksfoot and tall fescue than lucerne was a consequence of the photoperiodic requirement of the crops which favoured the development of plants differently in the summer period. Most two-factor interactions shown in **Table 4** were significant for all crops. The mean square variability existing among interaction factors resulted from different effects of agronomic treatments on the traits during the three years of evaluation. However, the lack of significance observed in the interactions G×I and I×Y in the trait dry matter and stem height in cocksfoot and I×Y in dry matter, stem m^{-2}, stem height and leaf stem ratio in tall fescue, was due to spring vegetative stasis of the grasses crops which reduced the effect of irrigation (**Table 4**).

The dry matter means differences over the three years of irrigated treatment was 24.34, 11.83 and 12.54 t ha^{-1} higher than the rainfed treatment in lucerne, cocksfoot and tall fescue, respectively (**Table 5**). The mean values of traits, in all forage crops under irrigation, showed low variation among years while under rainfed the difference between mean value of traits of the first year (Y1) was reduced from those of the third (Y3) in lucerne (mean of Y1 was 82, 41, 56 and 4% higher than those of Y3 for dry matter, stem height, stems m^{-2} and leaf: stem ratio, respectively), cocksfoot (mean value of Y1: 75% higher in dry matter, 40% in stem height, 41% in stems m^{-2} and 1% in leaf: stem ratio

Table 4 Mean square and significance of treatment effect on the traits dry matter, stem height, stem m^{-2} and leaf: stem ratio (%) in lucerne, cocksfoot and tall fescue under irrigated and rainfed treatments in the first and second harvests and 1996, 1997 and 1998 years of evaluation in Mediterranean environment.

Source of variation	df	Dry matter [a]	Stem height [b]	Stems density [c]	Leaf: stem ratio [d]
Lucerne					
Irrigation (I)	1	5315 **	16438 **	248 **	2075**
Year (Y)	2	287 **	2408 **	314 **	1789**
Harvest (H)	1	1241 **	442 **	206 **	1225**
Genotype (G)	9	124.9 **	242 **	63 **	126**
Inter (G×H)	9	61.3 **	60.4 *	44.2 **	22 *
Inter (G×I)	9	35.8 *	59.5 **	61.1 **	126 **
Inter (G×Y)	18	172.7**	32.7 **	81.7 **	20 *
Inter (H×I)	1	1601 **	12948 **	157 **	1808**
Inter (I×Y)	2	1124 **	454 **	917 **	579**
Inter (H×Y)	2	3248 **	16818 **	116 **	1356**
Pooled error	412	21.7	40.1	16.3	11
Cocksfoot					
Irrigation (I)	1	1132 **	6064 **	3566 **	356 **
Year (Y)	2	1249 **	3410 **	2019 **	452 **
Harvest (H)	1	166242 **	118722 **	6892 **	452 **
Genotype (G)	7	556 **	447**	1025 **	696 **
Inter (G×H)	7	490.2 **	1165 **	386 **	356 *
Inter (G×I)	7	27.5 ns	54 ns	65.9 *	459 **
Inter (G×Y)	14	316.5 **	275 **	158 **	451 **
Inter (H×I)	1	899 **	3232 **	596	689 **
Inter (H×Y)	2	4463 **	1301 **	4477 **	345 **
Inter (I×Y)	2	570.1 **	1221 **	230 **	653 **
Pooled error	336	60.7	79.6	63	51.1
Tall fescue					
Irrigation (I)	1	4688 **	2524 **	2341 **	648 **
Year (Y)	2	15693 **	10654 **	6787 **	595 **
Harvest (H)	1	151891 **	51084 **	518 **	346 **
Genotype (G)	6	1215 **	576 **	1388 **	456 **
Inter (G×H)	6	2801 **	428 **	765 **	143 *
Inter (G×I)	6	407 **	234 **	194 **	589 **
Inter (G×Y)	12	1058 **	306 **	350 **	349 **
Inter (H×I)	1	1333 **	239 *	5.5 ns	489 **
Inter (H×Y)	2	24038 **	6911 **	623 **	152 *
Inter (I×Y)	2	31.5 ns	154 ns	16 ns	37.2 ns
Pooled error	293	137.7	87	178	52.1

* and ** statistically significant at $P < 0.05$ and 0.001 level of probability.

[a] = t ha^{-1}

[b] = cm

[c] = stems m^{-2} . Real value equal actual value reported in column x 10^{3}

[d] = ratio of leaf over stem express in percentage

Table 5 Mean square and significance of treatment effect on the traits dry matter, stem height, stem m^{-2} and leaf: stem ratio (%) in lucerne, cocksfoot and tall fescue under irrigated and rainfed treatments in the first and second harvests and 1996, 1997 and 1998 years of evaluation in Mediterranean environment.

	Dry matter [a]		**Stem height** [b]		**Stems density** [c]		**Leaf: stem ratio** [d]	
	Irrigated	**Rainfed**	**Irrigated**	**Rainfed**	**Irrigated**	**Rainfed**	**Irrigated**	**Rainfed**
Lucerne								
Year								
Y1	28.22 a*	9.48 b	74 a	73 a	455 a	456 a	54.2 b	56.1 a
Y2	29.68 a	3.41 b	78 a	61 b	490 a	326 b	49.8 b	53.9 a
Y3	29.81 a	1.70 b	77 a	43 b	454 a	203 b	50.7 b	54.1 a
Mean	29.23	4.88	76	59	466	328	51.6	54.7
$LSD_{0.05}$	1.13	2.43	2	3	5	6	2.1	2.0
Harvest								
HI-R 1	5.22 a	3.01 b	70 a	69 a	452 a	416 b	49.5 a	50.7 a
HI-R 2	5.09 a	1.88 b	78 a	49 b	447 a	241 b	45.2 b	51.2 a
Mean	5.16	2.44	74	59	450	329	47.4	51.0
$LSD_{0.05}$	0.12	0.13	1	2	5	6	2.1	ns
Cocksfoot								
Year								
Y1	17.13 a	8.84 b	67 a	52 b	871 a	894 a	60.7 a	61.0 a
Y2	18.62 a	4.98 b	70 a	43 b	840 a	659 b	59.1 b	61.5 a
Y3	15.37 a	2.21 b	69 a	31 b	795 a	527 b	58.3 b	60.5 a
Mean	17.04	5.23	69	46	835	693	59.4	60.0
$LSD_{0.05}$	1.38	2.42	1	2	35	58	1.2	ns
Harvest								
HI-R 1	7.02 a	4.79 a	89 a	59 b	855 a	861 a	59.7 a	58.0 a
HI-R 2	4.48 a	0.57 b	62 a	19 b	765 a	525 b	57.7 b	63.5 a
Mean	4.62	2.68	63	39	748	693	58.7	60.8
$LSD_{0.05}$	0.27	0.27	3	3	26	39	1.2	1.8
Tall fescue								
Year								
Y1	18.69 a	9.28 b	69 a	58 b	923 a	883 a	54.1 a	47.8 b
Y2	19.59 a	6.99 b	70 a	41 b	967 a	642 b	52.6 a	46.5 b
Y3	19.66 a	4.64 b	68 a	20 b	831 a	301 b	54.9 a	46.1 b
Mean	19.31	6.97	69	40	907	609	53.9	48.5
$LSD_{0.05}$	1.09	2.39	ns	12	51	98	1.4	ns
Harvest								
HI-R 1	8.51 a	5.97 b	95 a	64 b	835 a	780 b	43.4 a	40.8 b
HI-R 2	6.60 a	0.97 a	56 a	16 b	829 a	437 b	51.6 a	43.4 b
Mean	5.97	3.48	60	40	783	608	48.5	42.1
$LSD_{0.05}$	0.30	0.34	3	3	55	69	1.2	1.5

* Mean with the same letter across irrigation treatment did not differ at $P<0.05$ probability level at Duncan's Multiple Range Test. ns= Not statistical significant.

¶ Mean of trait within the harvest treatments over the years of evaluations and genotypes of the forage perennial crop were tested with Last Significance Difference Test at $P<0.0$ level of probability.

[a] = t ha^{-1}

[b] = cm

[c] = stems m^{-2} . Real value equal actual value reported in column x 10^3

[d] = ratio of leaf over stem express in percentage

than those Y3) and tall fescue (mean of Y1: 51, 66 and 4% higher than the value of Y3 for the traits dry matter, both stem height and stems m^{-2} and leaf: stem ratio, respectively) (**Table 5**).

The effect of rainfed on stems m^{-2}, in all crops, in the first year of evaluation, was statistically not significant from those of irrigated condition while in Y2 and Y3 strongly stressed plant density reduced stems m^{-2} by 130 and 253 in lucerne, 235 and 367 in cocksfoot and 241 and 582 in tall fescue, respectively (**Table 5**). In contrast, the effect of water supply favoured the maintenance of plant density in all crops. The difference in stems m^{-2} between the mean of Y1 and Y3 under irrigated condition showed less variation (36 stems m^{-2} in lucerne, 76 in cocksfoot and 92 in tall fescue) than rainfed condition (205, 207 and 278 stems m^{-2} in lucerne, cocksfoot and tall fescue, respectively).

Because the effect of rainfed, when compared to irrigated condition during the three years' irrigation vs. rainfed evaluation, reduced the overall mean of stem height by 22.3% in lucerne and cocksfoot and 15.9% in tall fescue higher than the leaf: stem ratio (mean of leaf: stem ratio 5.7% higher in lucerne, 1.5% higher in cocksfoot and 10% lower in tall fescue than irrigated condition), there was a higher tendency for stem elongation than leaf development among forage crops (**Table 5**).

The effect of rainfed on the second harvest (HI-R 2) reduced the content of the first harvest (HI-R 1) in lucerne, cocksfoot and tall fescue, respectively by 1.13, 4.22 and 5.0 t ha^{-1} in dry matter; 20, 40 and 48 cm in stem height; 175, 336 and 343 stems m^{-2} in stem density and 0.5, 5.5 and 2.6 the percentage of leaf: stem ratio (**Table 5**). By contrast under irrigated condition, the difference in means of lucerne, cocksfoot and tall fescue among the three years of evaluation showed faint, non-significant variation (**Table 5**).

Irrigation effect on forage crop growth

The ANOVA traits of water supply treatment in all forage crops revealed a significant effect in all main factors (**Table 6**). Among them, harvest management produced more significant differences in dry matter and stem height than other traits in all forage crops. The wider variation of the harvest effect was due to different adaptability of the growing *habitus* of the three forage crops (spring in cocksfoot and tall fescue and spring-summer in lucerne) (**Table 6**). However, the lower variability observed across the years of evaluation and harvests in lucerne than cocksfoot and tall fescue was due to the effect of WUE of the water supplied (**Table 3**) and vegetative stasis which interfered with irrigation with a consequent influence of plant development among harvests (**Table 6**). The two-factor interactions were significant for all traits, which resulted from the effect of

Table 6 Main factors and two factors interaction mean squares of genotypes under irrigated condition in the perennial forage crops across the years of evaluation and harvests in Mediterranean environment.

Source of variation	df	Dry matter [a]	Stem height [b]	Stems density [c]	Leaf: stem ratio [d]
Lucerne					
Year (Y)	5	1719 **	2403 **	1625 **	6033 **
Error a	15	31.5	701.5	23.1	30.0
Harvest (H)	5	1634 **	18882 **	801**	3023 **
Error b	60	24.7	736.0	8.7	20.2
Genotype (G)	9	52 **	3310 **	120 **	175 **
Inter (G×H)	45	29 **	633 *	22 **	19.9 **
Inter (G×Y)	45	17 **	705 *	9 **	21.7 **
Inter (H×Y)	25	582 **	2788 **	163 **	4443 **
Pooled error	1302	11.8	381	6.6	9.2
Cocksfoot					
Year (Y)	5	4497 **	4423 **	18562 **	1767 **
Error a	15	66.9	113.6	172.858	129.3
Harvest (H)	2	51073 **	57186 **	3560 **	6039 **
Error b	36	64.2	109.3	413.4	62.9
Genotype (G)	7	531**	379 **	954 *	828 **
Inter (G×H)	14	137 **	352 **	910 *	112.3 **
Inter (G×Y)	35	67 **	139 **	771 *	168.9 **
Inter (H×Y)	10	3304 **	5582 **	2687 **	2500 **
Pooled error	499	54.7	90.6	486	48.8
Tall fescue					
Year (Y)	5	5526 **	2024 **	1065 **	2606 **
Error a	15	818	154.8	203.9	3.8
Harvest (H)	2	68251 **	73056 **	219 **	11182 **
Error b	36	106.6	55.5	92.1	52.2
Genotype (G)	6	1011 **	109 **	1046 **	4003 **
Inter (G×H)	12	1069 **	307 **	166 **	3515 **
Inter (G×Y)	30	328 **	191 **	534 **	3605 **
Inter (H×Y)	10	7741**	3355 **	2318 **	2229 **
Pooled error	324	63	46	77	62

* and ** statistically significant at $P< 0.05$ and 0.001 level of probability

[a] = t ha^{-1}

[b] = cm

[c] = stems m^{-2}. Real value equal actual value reported in column × 10^3

[d] = ratio of leaf over stem express in percentage

agronomic harvest management on genotypes of the forage crops across the years of evaluation (**Table 6**).

The effect of irrigation on crops, in comparison to rainfed, doubled the period of agronomic utilization (3 and 6 years under rainfed and irrigated growing condition, respectively) and biomass availability within the year (number of harvests per year: two in all crops under rainfed; three in cocksfoot and tall fescue and six for lucerne under irrigated) (**Table 2**).

The mean of traits assessed over the period under irrigated condition and those of rainfed was 81.7, 61.6 and 61.1% in dry matter, 13.0, 38.1 and 40.3% in stem height and 14.4, 7.5 and 22.3% in stems m^{-2} in lucerne, cocksfoot and tall fescue, respectively. The leaf: stem ratio under irrigated vs. rainfed treatment was significantly affected in lucerne and tall fescue (mean over the years 5.7% higher in lucerne and 10% lower in tall fescue than rainfed and irrigated treatment, respectively) (**Table 5, Fig. 2**).

Across the years of evaluation under irrigated condition, the trend of means showed, in all traits, a decreased value with an increase in the year of evaluation (**Fig. 2**). The dry matter mean of the first three years was 18.9, 37.6 and 14.7% higher than the mean of the following three years in lucerne, cocksfoot and tall fescue, respectively. The differences between the mean values of Y1 and Y6 of evaluation was 24.3, 19.4 and 10.1% in stem height; 45.3, 32.5 and 40.1% stems m^{-2} and 5.6, 9.8 and 1.9% in leaf stem ratio in lucerne, cocksfoot and tall fescue, respectively (**Fig. 2**). The trait stems m^{-2}, in all species, showed a heavier reduction from Y3 to Y6 of evaluation resulting in a reduction of dry matter, stem height and leaf: stem ratio (**Fig. 2**). Furthermore, the reduced plant stem development in Y2 and Y3 observed in cocksfoot and tall fescue, was ascribed to the increase of temperature and light exposition in the summer months (June to October) which favour vegetative stasis in cocksfoot and tall fescue rather than lucerne and as consequences reduced the effect of irrigation on stem development (**Fig. 3**). Thus, because irrigation treatment interfered with crops' photoperiod, reduced the regrowth of plant after defoliation and number of harvests, across the years of evaluation, in cocksfoot and tall fescue were 50% lower than lucerne (3 for grasses and 6 for lucerne) (**Fig. 3**). The effect of irrigation on traits in all forage crops was reduced as the number of harvests per year increased (**Fig. 3**).

The mean of traits of the third harvest (HI 3) in cocksfoot was 47.5 and 66.5% in dry matter; 38.7 and 57.3% in stem height and 18.4 and 27.1% in stems m^{-2}, lower than the second (HI 2) and first harvest (HI 1), respectively. In tall fescue, a similar trend of variation among traits was observed in the harvest of cocksfoot. In lucerne, the effect of harvest reduced the value of traits from HI 1 to HI 6 (mean of HI 6) was 47.7% lower in dry matter, 17.1% in stem height and 33.8% in stems m^{-2} than HI 1) (**Fig. 3**). An opposite trend was observed in the leaf: stem ratio, which increased across the harvest passing from 50% in HI 1 to 56% in HI 6, evidencing a prevailing leaf in the morphological architecture of the plant with an increase in harvest number. In contrast, in cocksfoot and tall fescue the leaf: stem ratio trait varied differently from HI 1 to HI 3 (leaf: stem ratio in HI 2 was 2.8% lower in cocksfoot and 17.3% higher and tall fescue than HI 1). Assessing the effect of different interactions between forage crops and photoperiod requirements, the content of HI 2 was reduced and increased by 25 and 3.3% in tall fescue and cocksfoot, respectively (**Fig. 3**).

Adaptability and performance of genotypes

The relationships among agronomic techniques (irrigation and harvests) during the years of evaluation on traits of

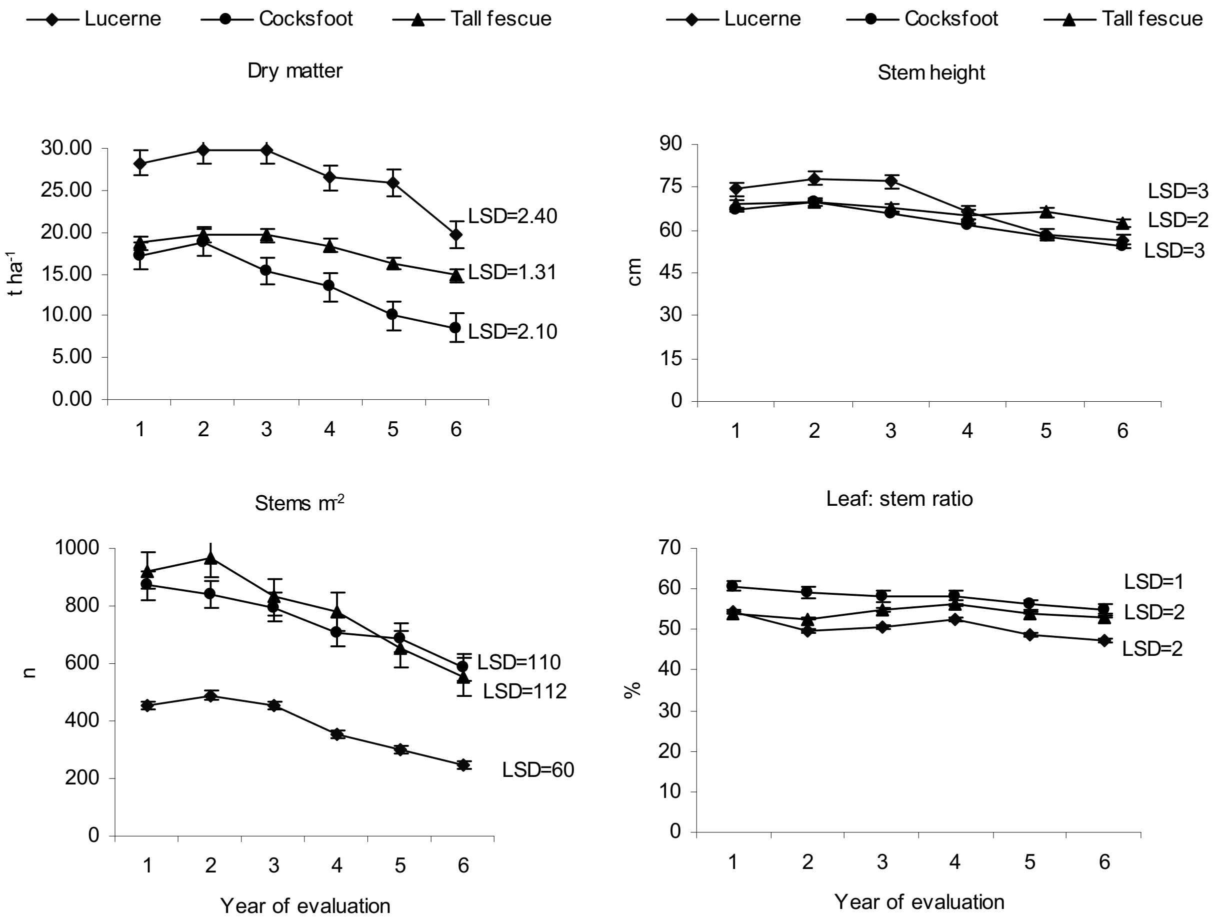

Fig. 2 Effect of year on the traits DM, stem height, stem m^{-2} and leaf: stem ratio across the period of evaluation lucerne, cocksfoot and tall fescue in perennial crops. The LSD reported in the picture of trait referred to *P*=0.05 level of probability. Error bars indicate SE of the mean.

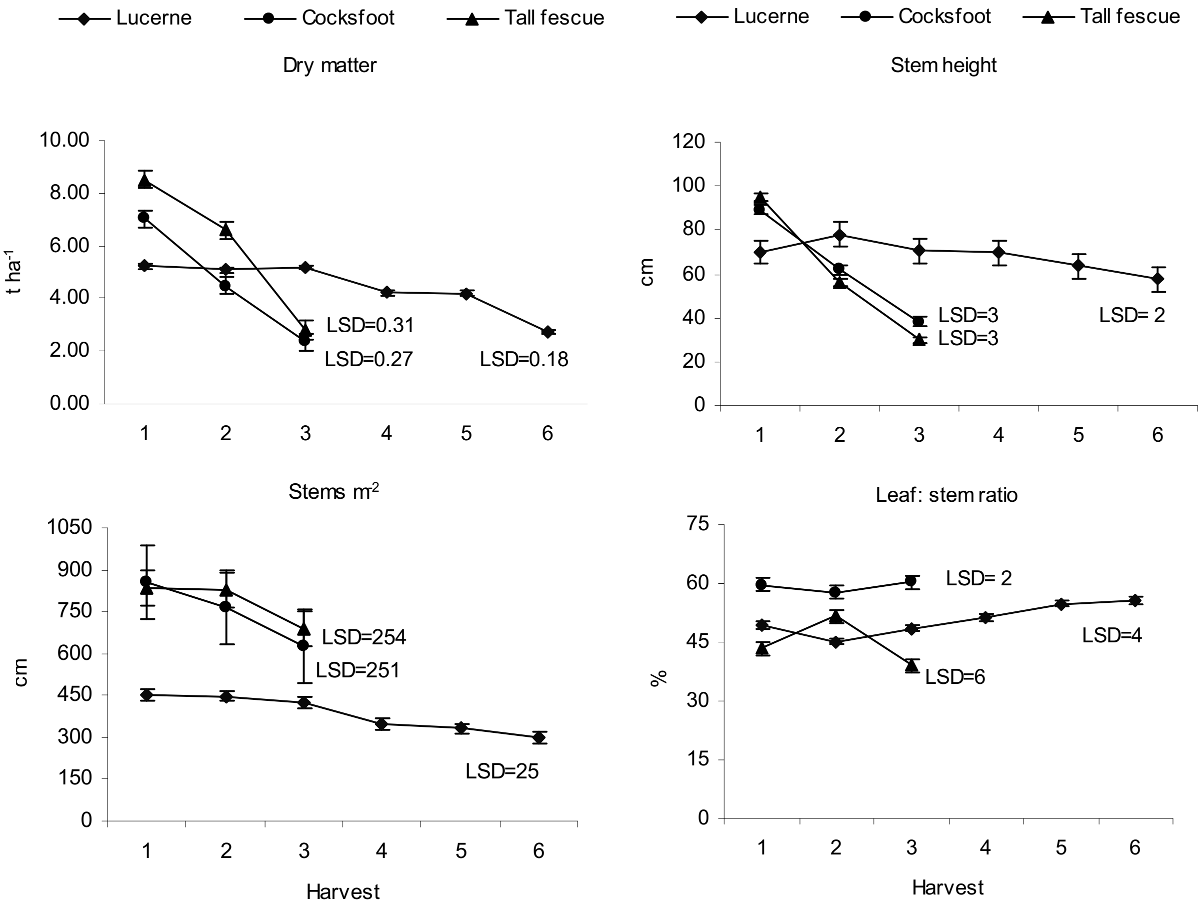

Fig. 3 Effect of harvest on the traits across the period of evaluation. The LSD of the traits reported in the frame, refers at P=0.05 level of probability. Error bars indicate SE of the mean.

Table 7 Yearly mean of perennial species of the trait dry matter, stem height, stem m^{-2} and leaf: stem ratio in the selected and discarded homogenous cluster group and mean of genotype in selected group over the period of evaluation under irrigated and rainfed growing condition in Mediterranean environment.

Genotype	Dry matter [a]		Stem height [b]		Stems density [c]		Leaf: stem ratio [d]	
	Irrigated	Rainfed	Irrigated	Rainfed	Irrigated	Rainfed	Irrigated	Rainfed
Lucerne								
Breeding population	26.84	5.29	70		411			
Cinna			68	60	403	351		
Coussouls	26.72	5.19			403	354	49.7	51.8
Equipe	27.13	4.98	71	58				51.3
Europe				58		382	48.9	51.2
Iside		4.99	73	63	400			
Lodi	26.73	4.98	70	59			49.2	53
Luzelle					409	383	49.2	52.3
Magalì	27.72		68	59		344		
Romagnola	26.63	4.88	73	62				
Mean								
Selected	26.96	5.10		60	405	363	49.1	51.9
Discarded	26.23	4.72		54	361	293	46.9	49.9
Cocksfoot								
Bepro					868	685		
Breeding population			64		799	793	62.1	63.1
Cambria	14.84	6.31	63	43	907		62.0	62.1
Cesarina	16.43	6.82	68	44	788	762	63.1	63.6
Lodola								
Luna Roskilde								
Lutezia						696		
Padania	15.25	6.22	68	41			66.7	68.5
Mean								
Selected	15.51	6.45	66		841	734		63.2
Discarded	11.23	5.31	60		651	651		57.1
Tall fescue								
Breeding population	19.18	8.38	79	44	934	881	55.9	
Lince					907			
Magno	19.38		71		824			48.1
Maris Kasba	18.99	8.16	68	41		671	55.1	49.3
Penna	18.38		69		791			
Sibilla								
Tanit	18.19	9.37	69	44		778	57.6	47.4
Mean								
Selected	18.82	8.64	71	43	864	777	56.12	48.2
Discarded	15.84	5.83	58	37	677	483	52.7	43.2

[a] = t ha^{-1}

[b] = cm

[c] = stems m^{-2}

[d] = ratio of leaf over stem express in percentage

lucerne, cocksfoot and tall fescue genotypes were evidenced by higher significant values of most of the three- or four-factor interactions (data not shown). The cluster analysis (Scott and Knott 1974) of traits recorded during the period of field evaluation, separate high from low performing genotypes within forage crop species. The analysis identifies, on the basis of the likelihood ratio test, two cluster groups with a number of independent genotypes having homogeneous and minimized mean square interaction among agronomic factors on genotypes. The lucerne, cocksfoot and tall fescue genotypes included in the selected cluster group of dry matter, stem height, stems m^{-2} and the leaf: stem ratio genotypes were endowed by a physiological peculiarity able to better cope with the unlikely interaction effect of weather condition and experimental treatments on genotypes (**Table 7**). The percentage of total number of genotypes belonging to a selected cluster of dry matter under irrigated and rainfed conditions were 60% in lucerne, 37.5% in cocksfoot and 71.4% in tall fescue. In all traits, tall fescue was the crop with the higher number of genotypes in the selected group rather than other crops (**Table 7**). Furthermore, because the varieties Coussouls, Equipe, Lodi and Romagnola in lucerne; Cesarina and breeding population in cocksfoot and Maris Kasba, Tanit and breeding population in tall fescue are included in more than one selected group, they may be better adapted to cope with the weather conditions of the Mediterranean environment.

DISCUSSION

Irrigation vs. rainfed effect on crop growth

Irrigation effect, in the environment, is characterized by the weather condition (**Fig. 1**), favours physiological mechanisms able to reduce the effect of summer stasis of vegetative growth (Eastin and Sullivan 1988; Denison and Perry 1990; Peterson *et al.* 1992; Doll 2002; Pimentel 2004; Fageria *et al.* 2006). However, the genotypes of cocksfoot and tall fescue, because present higher edaphic physiological characteristics to favour summer vegetative stasis than lucerne the biological activity processes of relocation of photosynthetic compounds to stems, during the month June to October were strongly reduced (Fairbourn 1982; Stanhill 1987; Pimentel *et al.* 2004; Deng *et al.* 2006) (**Fig. 3**). Thus, the effect of water applied by irrigation on genotypes of cocksfoot and tall fescue, because they had photosynthetic activity and relocation of biochemical compounds reduced, presented lower WUE than lucerne genotypes (**Table 3**).

The WUE average over the years of evaluation in lucerne genotypes was 57.5 and 40.8% higher than that of cocksfoot and tall fescue, respectively. The discrepancy in WUE between grasses (**Table 3**) was a consequences of a more adapted and efficient metabolic process of tall fescue rather than cocksfoot crops (Wardle and Peltzer 2003; de Boeck *et al.* 2008).

Difference between WUE means of rainfed and irrigated treatments, as reported by Zannone *et al.* (1983), Arcioni *et al.* (1996), Genter *et al.* (1997), Doll (2002) and Pimentel (2004), was due to reduction in water availability of rainfed condition which stressed the relocation of photosynthates to organs of the plant required for dry matter production, stem growth and restoration of root reserves causing a reduction of the agronomic period for crop utilization (**Table 2**) and collapse of the plants (**Table 5**).

All forage crops under rainfed, in the first year (Y1) of evaluation showed similar dry matter (data not shown) yield of irrigated condition while in the following years yield production was reduced in the second (Y2) and third (Y3) years by 64.2 and 82.1%, respectively in lucerne, 43.2 and 75% in cocksfoot and by 30.1 and 50.5% in tall fescue (**Table 5**). Furthermore, the dry matter produced in the first harvest under rainfed (HI-R 1) was 37.5% higher than the second harvest (HI-R 2) in lucerne, 88.1% in cocksfoot and 83.8% in tall fescue (**Table 5**). According to Martiniello (1998), Lloveras (1998), Fageria *et al.* (2006) and Lemmens *et al.* (2006) the effect of rainfed on dry matter of crops across the years of evaluation was mainly due to reduction of stems m^{-2} (stems m^{-2} in Y1 was 55, 41 and 66% higher than Y3, respectively in lucerne, cocksfoot and tall fescue) due to the collapse of plants in the meadow, stem development as an effect of internode elongation (stem height was 51.3, 33.3 and 40.2% shorter in Y1 than Y3 in lucerne, cocksfoot and tall fescue, respectively) and reduction of leaf weight (leaf: stem ratio in Y1 3, 1.6 and 3.6% higher than Y3 in lucerne, cocksfoot and tall fescue) (**Table 5**).

The range of variation (difference between lower and higher values under rainfed vs. irrigated treatment) between the leaf: stem ratio trait was lower under rainfed across the years of evaluation (variation among harvests in leaf: stem ratio were, in rainfed and irrigated, 2 and 4.4 in lucerne, 1.0 and 2.4 in cocksfoot and 1.3 and 1.5 in tall fescue, respectively) than irrigated condition (**Table 5**). By contrast, under harvest the range of variation between the leaf: stem ratio trait of rainfed and irrigated treatment was related to crop species (leaf: stem ratio percentage range of variation reduced in rainfed vs. irrigated by 0.5 vs. 4.3 in lucerne and 2.6 vs. 8.2 in tall fescue and increased by 5.5 vs. 2.0 in cocksfoot) (**Table 5**). Variation in stem and leaf development response across the year of evaluation and harvests under irrigated and rainfed may be attributed to the effect of moisture stress on morphological characteristics of a plant's stem and leaves (Fageria *et al.* 2006; Turner *et al.* 2006, 2007) (**Table 5**).

Irrigation effect on plant growth

The water applied by irrigation to the studied perennial forage crops removes the effect of soil moisture stress, which hindered the physiological activity and relocation of photosyntates to root and stem organs of plant with a consequent increase of dry matter production (**Table 6**) and elongation of the period of agronomic exploitation (**Fig. 2**). According to the results of Eastin and Sullivan (1988), Pimentel *et al.* (2004), Fageria *et al.* (2006), Turner *et a*l. (2007) and de Boeck *et al.* (2008), the effect of irrigation favours the restoration of metabolic reserves of root compounds increasing stem persistence of the crops and WUE of the water applied. The main agronomic effect of irrigation, in comparison to rainfed, was the increased of year dry matter by 81.7, 61.6 and 60.9% in lucerne, cocksfoot and tall fescue, respectively (**Table 5, Fig. 2**).

The increase of dry matter across years under irrigated condition was mainly supported by stems m^{-2} and stem height. In agreement with Martiniello (1998), Lloveras (1998), Pimentel *et al.* (2004), Bonnett *et al.* (2006), Deng *et al.* (2006), Fageria *et al.* (2006), King (2006), King *et al.* (2006) and Turner *et al.* (2007) the decline of dry matter observed in lucerne, cocksfoot and tall fescue after the first three years was a consequences of senescing organs of plants which reduced the efficacy of metabolic processes (the mean of the first three harvests was reduced in HI 4, HI 5 and HI 6, respectively by 24.1, 35.8 and 47.1% in lucerne, 15.1, 17.4 and 32.4% in cocksfoot and 14.1, 28.2 and 391% in tall fescue) and stem density (mean difference between stems m^{-2} of Y1 and those of Y 6 was 206, 283 and 370 stems m^{-2} in lucerne, cocksfoot and tall fescue, respectively) (**Fig. 2**).

According to the results obtained on sugarcane (*Saccharum officinarum* L.) by Lakshmanan *et al.* (2006), a statistical significant reduction occurred in stems m^{-2} from Y4 to Y6 (stems m^{-2} in Y6 was 45, 32.5 and 40.1% lower than Y1 in lucerne, cocksfoot and tall fescue, respectively) was a consequence of the senescence effect on the root system which promoted the plants' death (**Fig. 2**).

The effect of irrigation treatment influenced the regrowth of stems after harvest among forage crops. In agreement with Carter and Sheaferr (1983) and Martiniello *et al.* (1997), Lloveras *et al.* (1998) and King (2006), the higher dry matter yield of lucerne than cocksfoot and tall fescue under irrigated condition was due to physiological sensitivity of plants to photoperiod in summer months. The distinctive photoperiod requirement of the crops studied favour physiological processes which enable the plant to differently utilize environmental resources (Lemmens *et al.* 2006; Turner *et al.* 2007). Interaction among environmental factors (photoperiod, temperature and water availability) affect differently the physiological process and sink-source relationships in leaf, stem and root organs of lucerne, cocksfoot and tall fescue plant (Purcell *et al.* 2002; Hunt 2003; Kalaji and Pietkiewicz 2004).

The different photoperiod requirements of the crops evaluated in the experiments favoured summer vegetative stasis whose effect was strongly expressed in HI 2 and HI 3 in cocksfoot and tall fescue and reduced across the harvests of lucerne during the growing seasons (Lloveras *et al.* 1998; Bonnet *et al.* 2006; King 2006) (**Fig. 3**).

The lower mean reductions of dry matter production of lucerne, cocksfoot and tall fescue of the harvests made in warmer (July-October) months than those of spring months (May-June) (21, 59 and 63% lower, respectively in lucerne, cocksfoot and tall fescue) may be ascribed to lower sensitivity to summer vegetative stasis than those of grasses which reduced the number of harvests per year of evaluation and metabolic routes of physiological process (3 harvests in grasses and 6 in lucerne) (**Fig. 3**).

Dry matter production of HI 1 was 36.2 and 66.5% higher in cocksfoot and 22.4 and 67.1% higher in tall fescue than HI 2 and HI 3, respectively while stem height and stems m^{-2}, in HI 2 and HI 3, an effect of feeble physiological activity, were reduced (stem height was 27 and 51 cm in cocksfoot and 39 and 65 cm in tall fescue lower than HI 1; stem m^{-2} was 7.1 and 27.2% lower in cocksfoot and 7.1 and 17.8% lower in tall fescue than HI 1) (**Fig. 3**).

The reduced effect of irrigation on leaf: stem ratio trait across HI 2 and HI 3 was due to photoperiod sensitivity of the grass crops which favour variation between leaves and stems in plant development in tall fescue unlike cocksfoot while in lucerne, the effect of irrigation favours stem regrowth with a constant and statistically significant increase after HI 2 (from 45% in HI 2 to 56% in HI 6) of the leaf component over the stem (**Fig. 3**).

Adaptability of forage crop genotypes

The genotypes among forage crops of both growing conditions adapted differently to the weather conditions and the agronomic techniques of management. The statistical procedure of Scott and Knott (1974) may be considered an appropriate approach able to discover the genotypes endowed with physiological mechanisms able to perform better and exploit the environmental conditions of the experiment. In agreement with the inferences of Murphy *et al.* (1997) made on homogeneous Kentucky bluegrass (*Poa pratensis* L.) and Tawaha *et al.* (2005) in chickpea (*Cicer arietinum* L.), the genotypes present in the selected cluster group may be expected to be endowed with a genetic mechanism able to better tolerate and perform in yearly weather resources (**Table 7**).

CONCLUSIONS

Genotypes of perennial species adapt differently to the climatic conditions of the environment. The effect of irrigation on perennial forage species was related to different sensitivity of plants to the photoperiod of summer months. The effect of irrigation on dry matter, stem height and stems m^{-2} among perennial forage crops was more evident in lucerne which was not influenced by the photoperiod of summer months. Thus, lucerne genotypes, in comparison to cocksfoot and tall fescue under available water irrigation, showed physiological mechanisms able to increase the WUE over the years of evaluation. The adopted Scott and Knott (1974) statistical method is useful to identify genotypes endowed by bioagronomic characteristics able to better exploit the resource of harsh environments. The released genotypes and breeding population, which were included in more than one selected group, showed low interaction to weather conditions and better performance in environments with a Mediterranean climate.

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