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AGRONOMIC EFFECTS ON THE PRODUCTIVITY AND COMPOSITION OF NATIVE PASTURELANDS IN THE MEDITERRANEAN REGION

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Abstract: Pasturelands in the Mediterranean region of southern Italy show considerable variation in biomass production and floristic composition. Experiments were undertaken in four sites to examine the effect of nitrogen and phosphorus fertilizer addition on biomass productivity and community composition of native pasturelands. The fertilizer treatments (60 N kg ha^{-1}, 80 P kg ha^{-1}, and N plus P at two rates of application: 20-44 and 32-70 kg ha^{-1} N and P respectively) were compared to unfertilized control plots. Fertilizer addition affected biomass production and community composition at all locations. Nitrogen treatment generally increased the biomass production of grasses, but forb species productivity declined. Phosphorus addition resulted in an increased abundance of legumes; other plant families showed reduced productivity, except grasses which increased in moister sites. The combined nitrogen and phosphorus applications increased overall agronomic fertility, with a result that biomass production increased. Moreover, the higher application rate had little effect on the floristic composition of these native pasturelands.

Introduction

The Mediterranean region includes approximately 2.1 millions of km^2 of land, of which some 390,000 km^2 are pasturelands and cultivated grasslands. Only 15% of the region is characterized as a 'true' Mediterranean climate; the remaining areas are considered temperate steppes and deserts (Le Houerou 1981, Papanastasis & Mansat 1996).

Southern Italy (i.e., the region from Latium to Calabria and the islands of Sardinia and Sicily) includes about 24,400 km^2 of pastureland, which represents 74% of the permanent pasture of the country (ISTA 1994). These lands occur on soils with a great potential of improvement, and 38% are found on soils suitable for regular agronomic use. Agricultural suitability in the region varies with slope, soil depth, topography and available soil moisture (Martiniello 1989).

Pasturelands in the Mediterranean region are characterized by cool, moist winters and warm, very dry summers. Climate and soil conditions are the main factors affecting herbage productivity and quality (Buxton & Mertens 1995; Sollenberger & Cherney 1995; Odoardi et al. 1996). Considerable variation in rainfall and temperature exists within the Mediterranean region, but optimum moisture never coincides with the thermic optimum for vegetative growth. The most productive species in the region are annual and perennial C3 grasses and forbs (Talamucci & Chaulet 1989; Papanastasis & Mansat 1996).

Pasture management involves the human manipulation of abiotic and biotic factors in order to promote the productivity of economically important animals and animal products. Herbage productivity is dependent on seasonal climate conditions, soil moisture, air temperature and solar radiation, all of which affect plant growth (Gutman 1978; Cereti et al. 1987). While large areas of permanent pastures have adequate plant cover, productivity is low since soil nutrients are limiting. Increased production of natural pastures is therefore dependent on appropriate management decisions, including preservation of soil fertility and the regular application of fertilizers (Barnes & Taylor 1985; Rohweder & Van Keuren 1985; Keen 1987; Martiniello et al. 1996).

With rising land prices and increased demands for meat and milk, pressure are great to increase food production. As a result, there is renewed interest in making pasturelands more productive and profitable (Rohweder & Van Keuren 1985; McCloud & Bula 1985; Keen 1987; Martiniello & Barbato 1994). Many approaches has been suggested to improve herbage production in pasturelands. Biological improvement involves promoting species that are more tolerant of grazing and better able to cope with the hot and dry climatic conditions. Although this approach is scientifically possible, there are few examples of its application (Burton 1987; Martiniello 1989). Such pasture 'renovations', which involve replacing the native flora with more desirable forage plants, may temporarily increase biomass production. However, after a few years the initial advantages achieved by these agronomic techniques are often lost, particularly on poor soils (Leonard et al. 1968; Heath & Kaiser 1985; Rohweder & Albrecht 1995). Standard agronomic practices such as irrigation and fertilization have commonly been used to increase the productivity and quality of natural turves (Sears

Table 1. Main climatic, geographical and soil characteristics of the study sites.

	Location							
	Experiment 1		Experiment 2		Experiment 3		Experiment 4	
	Climatic							
Month	Temperature mean (°C)	Rainfall (mm)	Temperature mean (°C)	Rainfall (mm)	Temperature mean (°C)	Rainfall (mm)	Temperature mean (°C)	Rainfall (mm)
January	2.3	97	6.2	55	3.5	82	3.6	75
February	2.8	75	6.8	49	3.6	67	3.7	69
March	4.6	65	9.1	49	6.5	66	5.9	52
April	8.1	73	12.6	50	8.8	65	9.0	50
May	12.6	66	17.4	52	13.3	65	13.8	49
June	15.7	56	22.0	33	17.0	41	17.8	40
July	18.2	30	24.6	27	19.6	33	20.4	45
August	19.0	25	24.7	25	20.0	32	20.9	43
September	15.5	35	20.8	46	16.6	55	17.5	32
October	10.9	46	15.1	69	11.7	91	12.7	58
November	7.3	70	11.1	71	8.1	95	8.2	54
December	3.6	80	7.5	68	4.8	94	5.1	68
	Geographical							
Altitude (m above sea level)	726		621		842		796	
Longitude E	15°15'		15°25'		15°18'		15°55'	
Latitude N	41°18'		41°13'		41°12'		41°11'	
De Martonne aridity index	35.3		24.0		37.1		29.5	
	Soil							
Sand (%)	45		21		19		19	
Silt (%)	26		46		32		46	
Loam (%)	29		33		49		35	
pH	7.3		7.2		7.0		7.2	
Organic matter (%)	4.6		4.9		5.0		3.2	
Total nitrogen (‰)	2.2		2.0		2.1		1.9	
Phosphorous (ppm)	18		13		21		18	
Potassium (ppm)	1054		848		1071		477	

et al. 1965; Nichols & Clanton 1985; Marsh 1987; Keen 1987; Trimarchi et al. 1989; Martiniello et al. 1996).

The objective of this study is to use experimental approaches to evaluate the effect of nitrogen and phosphorus fertilizer addition on the productivity and community composition of four pasturelands in southern Italy. The sites are characterized by a temperate Mediterranean climate.

Materials and Methods

The experiments were implemented in 1992 at four sites in the Apulia region of southern Italy: Celle S. Vito (experiment 1), Deliceto (experiment 2) and Monteleone di Puglia (experiment 3) are found in the Daunian Sub-Apennines mountain region, while the Monte Sant' Angelo (experiment 4) site occurs near the Gargano promontory. Climatic (Abatantuono et al. 1994, personal communication), geographic and soil characteristics of the four study sites are summarized in Table 1. The sites are included in a Mediterranean zone and have a meso-Mediterranean climate (UNESCO-FAO 1963). At each site, a randomly selected area of about 600 m^2 was chosen and isolated using metal netting and barbed wire to exclude grazing animals. Within each exclosure, five 100 m^2 plots were established and the following fertilizer treatments applied: C = control (no fertilizer applied); N = nitrogen (at a rate of 60 kg ha^{-1}, as urea); P = phosphorus (at a rate of 80 kg ha^{-1}, as superphosphate); L(N+P) = low nitrogen and phosphorus (at rates of 20 and 44 kg ha^{-1}, as ammonium-biphosphate); and H(N+P) = high nitrogen and phosphorus (at rates of 32 and 70 kg ha^{-1}, as ammonium-biphosphate). The data reported here are from the last three years of the experiments (1995-1997).

Fertilizer was applied to the plots in the first week of January. Prior to fertilization, four topsoil cores (to a depth of 40 cm) were taken from each plot for nutrient and soil classification analysis. Within each plot, plant biomass was harvested within four 1 m^2 quadrats twice per year. Species were sorted and identified (Fiore 1969a,b), and biomass was dried at 35 °C in a forced-ventilation oven to constant mass.

Data of replications, fertilizer treatments, year of evaluation, botanical families and species within families were considered in the analysis. A randomized complete block factorial analysis of variance (ANOVA) was used to analyze the data (Steel & Torrie 1980). The effect of mineral fertilization on floristic composition (plant family and species) was performed in all treatments between 1995 and 1997, using a mixed-model ANOVA with years and replications as random effects and fertilization treatment as a fixed effect. Percentage data were subjected to arc-sin transformation prior to analysis. The effect of year and fertilization treatments on dry biomass production, and botanical families and their interaction, were tested with an appropriate error term. Least significant differences (LSD) were calculated when a significant F-ratio was encountered. Families with more than 10 species were considered as independent groups (GR = Gramineae, LE = leguminous, CO = composites, LA = labiates and CA = Caryophyllaceae), while those with lower number of species (BO = Boraginaceae, CP = Campanulaceae, CR = Cruciferae, CY = Cyperaceae, DI = Dipsacaceae, EU = Euphorbiaceae, GE = Geraniaceae, LI = Liliaceae, PL = Plantaginaceae, PO = Polygonaceae, RA = Ranunculaceae, RI = Rinantaceae, RU = Rubiaceae, SC = Scrophulariaceae and UM = Umbelliferae) were included in a group termed 'miscellaneous'.

Replications of each experiment and fertilized treatment data were processed using cluster analysis, following the procedure described by Scott and Knott (1974). This analysis identified, on the basis of the likelihood ratio test, two cluster groups. Independent mean-square interactions among years within non-overlapping, statistically significant cluster groups were determined.

Results

Effect of Fertilizer on Biomass

The control treatment in the four study sites differed in dry matter yield (Table 2), ranging from 123. 6 g m^{-2} (experi-

Table 2. Dry biomass yield of pasture in the treatments evaluated in the four experiments in the three years of study.

Location	Treatment					Mean	LSD
	Control	N	P	L(N+P)	H(N+P)		0.05
	1995						
Experiment 1	144.3	260.9	356.5	288.5	298.7	269.8	25.1
Experiment 2	75.7	167.6	484.6	414.8	351.1	298.7	37.8
Experiment 3	239.1	286.4	250.4	357.8	391.1	323.0	29.4
Experiment 4	175.3	174.3	366.4	325.7	361.8	280.7	31.5
Mean	156.1	247.3	364.5	346.7	350.7	293.1	15.6
LSD 0.05	25.3	36.8	34.3	21.5	19.6	14.3	
	1996						
Experiment 1	170.6	365.7	397.3	454.8	446.0	366.9	23.2
Experiment 2	125.1	334.6	733.7	760.5	623.6	531.5	34.4
Experiment 3	206.1	235.4	328.4	348.2	258.3	275.3	27.2
Experiment 4	233.6	359.5	544.3	426.9	416.7	396.2	22.4
Mean	183.9	323.8	500.9	497.6	431.0	392.5	17.9
LSD 0.05	23.4	27.9	38.7	35.4	33.9	20.5	
	1997						
Experiment 1	202.0	315.7	331.4	407.7	385.9	328.5	14.9
Experiment 2	90.1	173.2	401.8	349.5	369.5	276.8	18.7
Experiment 3	141.9	200.9	233.2	360.0	331.3	253.5	21.4
Experiment 4	235.8	420.4	437.6	492.9	517.6	420.9	20.4
Mean	167.5	277.6	351.0	402.5	401.1	319.9	16.1
LSD 0.05	26.9	32.6	33.5	29.8	23.6		

Table 3. Percentage and number of species of the botanical family in the fertilized treatment considered in the experiment in the four sites involved.

Year and treatment	Gramineae		Leguminous		Composites		Labiates		Caryophillaceae		Miscellaneous		
	%	species (n.)	%	species (n.)	%	species (n.)	%	species (n.)	%	species (n.)	%	families (n.)	species (n.)
1995	Experiment 1												
Control	56.0	6	14.5	3	3.9	3	3.1	2	1.1	2	0.5	2	1
N	85.6	8	4..3	5	2.2	3	1.0	2			0.4	1	3
P	28.1	6	32.0	6	1.3	2	6.4	1	0.6	1	0.3	1	1
L(N+P)	46.7	7	26.5	4	2.5	6	0.1	1	1.0	1	0.2	2	2
H(N+P)	37.0	5	23.8	5	0.4	2	1.6	2			2.0	2	2
Mean	50.7		20.2		2.1		2.4		0.5		0.7		
LSD 0.05	6.7		2.5		1.1		1.2				0.7		
1996													
Control	70.1	5	20.3	3	0.2	1			0.5	1	2.0	2	2
N	85.9	6	1.7	2	6.6	4	2.9	1	0.4	1	0.4	1	1
P	50.6	4	30.3	4	1.1	1			0.4	1	5.1	1	1
L(N+P)	80.7	5	7.4	3	2.3	3	2.9	1					
L(N+P)	66.6	8	17.5	2	5.5	3	2.0	1	0.3	1	0.3	1	1
Mean	70.8		15.4		3.1		2.1		0.4		2.0		
LSD 0.05	6.7		3.5		1.6						1.5		
1997													
Control	65.6	4	27.4	4	0.9	2	6.1	2					
N	72.8	4	20.1	4	0.6	1	2.9	2					
P	38.3	2	43.8	2	0.7	2	4.5	2					
L(N+P)	48.4	4	44.2	2	1.1	3	2.6	2					
H(N+P)	44.1	5	33.2	2	0.3	1	6.2	2			0.2	1	1
Mean	53.8		33.7		0.8		4.5						
LSD 0.05	7.4		3.2				1.8						

ment 2) to 214. 9 g m^{-2} (experiment 4). Dry matter in 1996 was 23% greater than in 1995, and 18% greater than in 1997.

The fertilizer treatments affected dry matter yield in all experiments. Fertilizer effects were dependent on the prevailing environmental condition in the year of evaluation. The increase in dry matter of the fertilizer treatments relative to the control was 38% for N, and 57% for both P and (N+P) combined treatments. The experiment 2 site showed the greatest response to the fertilizer treatments in all years. The greatest effect of the (N+P) fertilizer treatments occurred in 1996 (41 and 47% greater than 1995 and 1997, respectively).

Effect of Fertilizer on Plant Families

In all experiments, the species belonging to GR and LE families (for codes see materials and method section or appendix) are the most representative and achieve the greatest contribution to the percentage of biomass production (Tables 3-6). In the control treatment, percentage of species in GR, LE, CO and LA varied by experiment: experiment 1 by 64, 21, 2 and 5% (Table 3); 18, 11, 13 and 10% in experiment 2 (Table 4); 56, 4, 2 and 1% in experiment 3 (Table 5); and 36, 22, 13 and 1% in experiment 4 (Table 6). The 'miscellaneous' family group also varied by experiment, from 8% in experiment 1 to 29% in experiment 4.

Compared to the control treatment, nitrogen addition affected species composition in all experiments, increasing the biomass of GR species while decreasing the LE, CO and LA species. The effect of phosphorus addition varied considerably by experiment. Compared to the controls, biomass increased by 35% in experiment 2 and 31% in experiment 4, but biomass declined in experiments 1 and 3 (25% and 29% respectively). The contrasting effect of the P-treatment on the GR flora may be ascribed to competition effects between GR and LE species. Increases in LE species under the P treatment (9% in experiment 1, 32% in experiment 3) resulted in the suppression of GR species (by 25% in both experiments). Changes in GR and LE species under the P-treatment was also observed in experiments 2 and 4. In these experiments, the increase of GR (35% in experiment 2, 31% in experiment 4) was a consequence of synergetic effects of LE on GR. The percentage of LE species in these experiments (23% in experiment 2, 13% in experiment 4) was lower than those of the other experiments (30% and 37% in experiments 1 and 3, respectively). The effect of P-treatment on species of CO, LA and the 'miscellaneous' families were less clear. The greatest influences were observed on species of CO in experiment 2 (10% lower than control), and the 'miscellaneous' families in experiment 4 (7% less than the control).

The two nitrogen and phosphorus treatments (N+P) differently affected floristic development in the GR, LE, CO and LA families. The lower nutrient treatment (L(N+P)) promoted the development of a higher number of species, particularly in the less well represented families (CO, LA and

Table 4. Percentage and number of species of the botanical family in the fertilized treatment considered in the experiment in the four sites involved.

Year and	Gramineae		Leguminous		Composites		Labiates		Caryophillaceae		Miscellaneous		
treatment	%	species (n.)	%	species (n.)	%	species (n.)	%	species (n.)	%	species (n.)	%	families (n.)	species (n.)
1995							Experiment 2						
Control	4.1	5	14.8	3	14.5	4	7.0	2	0.2	1	6.9	1	1
N	18.7	6	0.5	3	2.0	2	0.3	1	0.3	1	14.7	2	2
P	13.3	3	40.9	2	0.2	1					2.0	1	1
L(N+P)	20.8	5	21.9	6	2.4	2	0.1	1			0.2	1	1
H(N+P)	15.4	4	21.4	6	2.9	2			0.2	1	0.1	1	1
Mean	14.5		20.0		4.4		2.5		0.2		4.8		
LSD 0.05	4.2		4.8		2.3		3.2				2.4		
1996													
Control	21.3	4	1.8	3	3.8	3					31.0	2	2
N	49.3	4	0.8	2	18.1	5	0.2	1	0.2	1	8.3	1	1
P	52.5	4	21.0	2	6.8	3	1.6	1			5.1	1	2
L(N+P)	80.9	4	4.1	3	7.9	2					3.2	1	1
H(N+P)	59.4	4	17.4	3	4.3	4	1.9	1			3.2	1	1
Mean	52.7		9.0		8.2		1.2				10.3		
LSD 0.05	8.4		2.2		3.2						3.0		
1997													
Control	28.2	5	16.6	2	21.7	3	23.5	2					
N	52.6	6	0.5	6	7.6	3	18.4	1			21.1	1	2
P	92.8	7	6.5	4	0.7	3							
L(N+P)	86.2	10	10.9	5	1.8	2	1.2	2					
H(N+P)	76.6	6	17.6	4	5.8	5	0.1	1					
Mean	67.3		10.4		7.5		10.8						
LSD 0.05	7.4		4.1		3.1		4.3						

Table 5. Percentage and number of species of the botanical family in the fertilized treatment considered in the experiment in the four sites involved.

Year and	Gramineae		Leguminous		Composites		Labiates		Caryophillaceae		Miscellaneous		
treatment	%	species (n.)	%	species (n.)	%	species (n.)	%	species (n.)	%	species (n.)	%	families (n.)	species (n.)
1995							Experiment 3						
Control	42.9	9	3.1	6	0.2	1	0.1	1	0.4	1	27.6	4	5
N	33.6	10	1.1	2	1.1	3	7.1	2	1.5	1	40.6	6	7
P	21.8	8	26.3	7	1.9	3	0.9	1			2.3	4	4
L(N+P)	30.3	8	27.2	4	0.1	1	0.2	1			0.7	4	4
H(N+P)	20.7	6	26.8	4	2.2	3	0.3	2			3.8	3	3
Mean	29.9		16.9		1.1		1.7		0.9		15.0		
LSD 0.05	4.3		3.5				2.4				5.6		
1996													
Control	76.6	8	4.5	4	2.0	2					3.0	1	1
N	71.8	11	4.0	2	2.7	3	0.3	1			2.1	1	2
P	83.4	7	11.6	3	0.3	2							
L(N+P)	86.8	7	1.9	3	6.4	1					3.4	1	1
H(N+P)	76.5	6	9.4	4	7.7	3	0.6	1					
Mean	79.0		6.3		3.2		0.5				2.8		
L 0.05	4.2		3.9		2.3								
1997													
Control	48.1	8	44.8	2	2.7	2	2.0	2					
N	69.7	9	7.9	4	7.7	3	0.7	1			11.5	3	3
P	24.9	6	71.5	2	1.4	3	0.7	1			1.6	2	2
L(N+P)	25.7	9	53.3	4	0.6	2	0.7	1			0.7	1	1
H(N+P)	34.7	6	40.5	2	1.9	3					0.7	1	1
Mean	40.6		43.6		2.9		1.0				3.6		
LSD 0.05	6.4		4.1		2.7								

Table 6. Percentage and number of species of the botanical family in the fertilized treatment considered in the experiment in the four sites involved.

Year and treatment	Gramineae %	Gramineae species (n.)	Leguminous %	Leguminous species (n.)	Composites %	Composites species (n.)	Labiates %	Labiates species (n.)	Caryophillaceae %	Caryophillaceae species (n.)	Miscellaneous %	Miscellaneous families (n.)	Miscellaneous species (n.)
						Experiment 4							
1995													
Control	21.2	7	22.7	6	15.1	6	12.2	1	0.1	1	11.5	4	5
N	54.3	8	2.4	3	6.0	3			0.9	1	11.9	5	7
P	39.1	7	15.3	5	5.9	3	0.3	1			3.9	5	6
L(N+P)	51.2	9	14.0	5	1.5	3			3.9	2	4.1	4	6
H(N+P)	48.9	6	8.6	3	5.1	2	1.5	1	0.9	1	3.6	3	5
Mean	42.9		12.6		6.7		4.7		1.5		7.1		
LSD 0.05	6.7		4.5		3.4		2.8		2.4		2.5		
1996													
Control	35.6	3	21.6	5	2.0	2	0.2	1			6.0	4	5
N	47.2	6	11.7	9	2.2	5			0.6	1	8.7	4	6
P	66.8	7	10.1	4	0.2	1					2.8	1	2
L(N+P)	77.1	6	3.0	3	0.2	1					2.7	2	2
H(N+P)	78.0	8	3.6	4					0.3	1	0.9	2	2
Mean	70.4		10.0		1.2				0.5		4.2		
LSD 0.05	7.1		5.1								2.2		
1997													
Control	51.8	8	21.7	2	0.7	2					12.7	3	4
N	79.0	8	5.3	3	1.7	1			0.6	1	13.4	2	3
P	96.0	9	3.1	3							1.0	1	1
L(N+P)	95.2	10	1.0	3	0.5	2	3.1	2			0.7	2	3
H(N+P)	92.6	12	0.6	3	0.3	1					3.0	1	1
Mean	82.9		6.3		0.8				0.6		6.2		
LSD 0.05	7.4		3.1								2.8		

'miscellaneous'). Overall, these two treatments had less of an effect on floristic composition than the N and P treatments. The mean number of species was lower in the H(N+P) and L(N+P) compared to the control (mean over the years: -1 and -0. 4 in GR, 0. 2 and -0. 1 in LE, -0. 5 and 0. 5 in CO and -0. 5 and -0. 2 in LA). Compared to the control, GR was 10% lower and LE was 5% higher in experiment 1; 32% and 7% lower in experiment 2; 10% and 23% higher in experiment 3, and 35% lower and 7% higher in experiment 4. Other species remain unchanged, except for CO under experiments 2 and 4 (9% and 12% higher than control, respectively).

Effect of Fertilizer on Community Composition

Each experiment was characterized by a distinct floristic community. The number of species present ranged from 25 in experiment 3 to 29 in experiment 1. Shared species groups across the experiments were: GR-19, CO-05 and PL-02; GR-01, CO-15, CO-16 and CO-19 in three environments, and 3 species of GR and LA, 8 of LE and 2 of RU in two experiments (Tables 7-11). The flora most represented in the experiments, and comprised in the higher group of the cluster analysis, differed for the experiment and for botanical family. The largest group of higher selected species were: LE with four species in experiments 1 and 4; followed by the group of three species in GR (experiments 2 and 3), CO (experiments 2 and 4), 'miscellaneous' (experiments 1 and 3), two species of GR, LE and CO in two experiments and 1 species in LA and miscellaneous family in three and 1 experiments, respectively.

Compared to the control, nitrogen addition increased by 6% (mean over the experiments and years) the biomass of the species present in the families GR and LA, and reduced by 3% the CO family (Table 8). Furthermore, nitrogen addition promoted the development of LE-12 among the species of LE, and DI-01 in the DI family in experiment 1. In all experiments, the species belonging to the discarded group differed from those present in the control in the families of CO, LA, and CA.

Phosphorus fertilization promoted the development of LE species in both selected and discarded groups of the control treatment. The development of biomass in the species belonging in the higher cluster group of LE and GR was 3% and 5% lower and greater than those of the control, respectively. Two leguminous species of the higher cluster group in experiments 1-3 benefited from phosphorus addition, reducing the development of other species (Table 9). By contrast, in experiment 4, the species of LE in the higher cluster group are present in the flora of the control treatment. Phosphorus addition also promoted development of the number of species in the selected group of GR, and reduced the species in the discarded group (2 against 4) and the number of species present in the higher and discarded cluster group in the CO, LA, BO and PL families.

The combined nitrogen and phosphorus treatments interfered with the development of species number and biomass production in both higher and discarded cluster groups (Tables 10-11). The H(N+P), in comparison to L(N+P) treat-

Table 7. Species code comprised in the higher cluster group and those in the discarded group over the years of evaluation in the control treatment in locations of Mediterranean environments.

Treatment	Gramineae Species codes	%	Leguminous Species codes	%	Composites Species codes	%	Labiates Species codes	%	Miscellaneous Species codes	%
Control	Experiment 1									
	GR-19	76	LE-12	16	CO-05	36	LA-06	33	LI-02	60
	GR-21	10	LE-16	27	CO-16	39	LA-08	48	PL-02	15
			LE-19	25					RU-02	12
			LE-27	22						
Mean species										
Selected		86		90		75		81		87
Discarded species	GR-10; GR-13 GR-22; GR-24		LE-23; LE-22 LE-07		CO-15		LA-09; LA-03;		CA-02; RU-04; BO-01; BO-02	
Mean		14		14		25		19		13
Control	Experiment 2									
	GR-18	46	LE-22	26	CO-05	54	LA-02	80	PL-02	78
	GR-19	24	LE-33	47	CO-16	26			UM-07	16
	GR-01	20			CO-15	11				
Mean species										
Selected		90		73		91				94
Discarded species	GR-03; GR-06; GR-15; GR-28		LE-08; LE-09; LE-16; LE-23		CO-02; CO-06; CO-09; CO-19		LA-10; LA-11	80	CY-01; PL-03	
Mean		10		27		8		20		7
Control	Experiment 3									
	GR-30	37	LE-11	73	CO-05	51	LA-03	56	PL-02	69
	GR-19	18	LE-01	13	CO-19	28	LA-06	40		
	GR-15	8								
Mean species										
Selected		63		86		79		96		87
Discarded species	GR-25; GR-01 GR-06; GR-27		LE-04; LE-14; LE-09; LE-19		CO-02 CO-07		LA-02;		CA-01; UM-01; BO-01; PL-01	
Mean		37		14		21		4		31
Control	Experiment 4									
	GR-03	58	LE-14	31	CO-19	46			LA-07	24
	GR-01	18	LE-33	20	CO-05	20			RU-02	21
			LE-26	18	CO-02	15			LA-03	18
			LE-11	12						
Mean species										
Selected		76		81		81				63
Discarded species	GR-02; GR-06; GR-19; GR-23		LE-21; LE-25; LE-04; LE-08		CO-08; CO-16; CO-15				PL-01; PL-02; PO-01; PA-01	
Mean		24		19		19		20		37

ment, achieves an increase of the number of species of LE in the discarded group of experiment 1, and in the higher cluster group of the other experiments. H(N+P) also increased, in both selected and discarded cluster group, the species in the families LA, BO and SC in experiment 1, CY in experiment 2, LI, RA and RU in experiment 3, and CR in experiment 4. In addition, higher nutrient levels suppressed species in the families EU and GE in experiment 3, and RU in experiment 4. Overall, the H(N+P) treatment resulted in fewer changes in community composition than the other fertilizer treatments. Compared to the control, the number of species (mean over all years and experiments) was reduced by 15%, 17%, 15% and 6% for the treatment N, P, L(N+P) and H(N+P), respectively.

Table 8. Species code comprised in the higher cluster group and those in the discarded group over the years of evaluation in the nitrogen treatment in locations of the Mediterranean environments.

Treatment	Gramineae Species codes	%	Leguminous Species codes	%	Composites Species codes	%	Labiates Species codes	%	Miscellaneous Species codes	%
N					Experiment 1					
	GR-19	83	LE-12	75	CO-05	32	LA-05	54	BO-01	32
	GR-21	7	LE-08	8	CO-06	27	LA-02	32	CA-02	25
			LE-33	9	CO-16	26			DI-01	22
Mean species Selected		90		92		75		86		79
Discarded species	GR-01; GR-09 GR-33;		LE-18; LE-19		CO-19				CA-01; RU-02	
Mean		10		18		14				21
N					Experiment 2					
	GR-19	75	LE-16	27	CO-06	56	LA-03	98	PL-02	62
	GR-01	8	LE-35	47	CO-16	25			SC-01	19
			LE-12	16						
Mean species Selected		83		90		81		98		81
Discarded species	GR-03; GR-28; GR-06; GR-23		LE-01; LE-23		CO-19; CO-08; CO-15; CO-03		LA-01; LA-06		PL-01; PL-03	
Mean		17		10		19		2		19
N					Experiment 3					
	GR-05	32	LE-23	29	CO-19	63			LA-06	47
	GR-03	20	LE-28	28	CO-22	15			BO-01	19
	GR-01	17	LE-33	14					PL-01	14
	GR-06	11								
Mean species Selected		80		71		78		86		80
Discarded species	GR-24; GR-19 GR-15		LE-01; LE-11 LE-17; LE-09		CO-05; CO-06; CO-16; CO-02				RA-01;CA-01; PL-02; PL-03	
Mean		18		28		22				20
N					Experiment 4					
	GR-02	49	LE-26	31	CO-14	33			PL-01	45
	GR-03	21	LE-21	25	CO-15	29			PL-02	24
	GR-01	16	LE-19	19	CO-19	18			RU-03	8
			LE-11	12					PL-03	7
Mean species Selected		86		88		80				84
Discarded species	GR-06; GR-19; GR-07; GR-04		LE-04; LE-14; LE-33; LE-17		CO-06; CO-05; CO-15				RU-02; CA-01; CR-01; PO-01	
Mean		14		12		20				26

Discussion

Annual dry matter production during the study period was correlated with an aridity index (r= 0. 58), suggesting that development of the natural flora is dependent on rainfall and temperature during the growing season (De Martonne 1926). Species in the families GR, LE and CO were common in all experiments. Species in the LA, CA and 'miscellaneous' family contributed lower percentages of biomass production. The flora of the four experiments differed substantially (Table 7). This variation is likely attributable to differing environmental conditions, historical factors, and interspecific competitive effects (Ripley 1992).

Table 9. Species code comprised in the higher cluster group and those in the discarded group over the years of evaluation in phosphorous treatment in the locations of the Mediterranean environments.

Treatment	Gramineae		Leguminous		Composites		Labiates		Miscellaneous	
	Species codes	%	Species codes	%	Species codes	%	Species codes	%	Species codes	%
P					Experiment 1					
	GR-19	66	LE-33	41	CO-04	94	LA-03	61	BO-01	83
	GR-21	12	LE-08	39						
	GR-13	12								
Meam species										
Selected		90		80		94				83
Discarded	GR-01;		LE-23;LE-16;CO-16;				LA-06;		PL-02; CA-01;	
	GR-24		LE-18				LA-07		CA-02	
Mean		10		20		6		39		17
P					Experiment 2					
	GR-01	53	LE-07	49	CO-04	94			PL-02	58
	GR-24	24	LE-26	40						
	GR-16	16								
Meam species										
Selected		93		89		94				58
Discarded	GR-34;		LE-10; LE-33;		CO-19; CO-15;				LA-02;	
	GR-26		LE-11; LE-14CO-02						PL-03	
Mean		6		11		6				42
P					Experiment 3					
	GR-19	27	LE-23	42	CO-15	47			LA-06	31
	GR-35	19	LE-33	19	CO-19	37			PL-01	30
	GR-06	15	LE-09	14					BO-02	23
	GR-01	13								
Meam species										
Selected		74		76		84				84
Discarded	GR-05; GR-04;		LE-11; LE-21;		CO-05;				PL-03;	
	GR-36; GR-02		LE-01; LE-37CO-07						RA-01	
Mean		26		24		18				16
P					Experiment 4					
	GR-02	42	LE-26	49	CO-19	43			DI-01	36
	GR-03	20	LE-25	40	CO-04	32			PL-03	23
	GR-01	16	LE-27	19	CO-09	21			PA-01	20
			LE-14	13					PL-01	17
Meam species										
Selected		78		84		96				96
Discarded	GR-06; GR-07;		LE-17; LE-09;		CO-05				PL-02; CR-01;	
	GR-12; GR-29		LE-24; LE-01;						PO-01	
Mean		21		16		4				4

Fertilizer treatments increased dry matter production in these natural pasturelands (cf. Sears et al. 1965; Keen 1987; Rohweder et al. 1995; Martiniello et al. 1996). The N, P and combined (N+P) treatments increased biomass to different degrees (40% in N, and 58% in P and combined N+P treatments). Fertilizer treatments also differentially affected species composition and community development in the experiments. As reported by Miller & Reetz (1995), nitrogen addition increased the biomass production in GR species (ranging from 8-24% greater than the control in the four experiments). This may be attributable to the more efficient utilization of nitrogen by GR species. The growth of species from other families may have been adversely affected by prevailing soil characteristics and weather condition (Tables

Table 10. Species code comprised in the higher cluster group and those in the discarded group over the years of evaluation in the L(N+P) treatment in the locations of the Mediterranean environments.

Treatment	Gramineae Species codes	%	Leguminous Species codes	%	Composites Species codes	%	Labiates Species codes	%	Miscellaneous Species codes	%
L(N+P)	Experiment 1									
	GR-19	53	LE-33	61	CO-16	30			LA-06	82
	GR-06	24	LE-08	33	CO-05	25				
					CO-04	14				
Mean species										
Selected		77		94		69				82
Discarded	GR-01; GR-13; GR-21; GR-24		LE-17; LE-19; LE23		CO-15; CO-19				CA-02; PL-02; SC-01; LA-07; RU-02	
Mean		23		6		31				18
L(N+P)	Experiment 2									
	GR-01	43	LE-10	40	CO-05	70			PL-02	84
	GR-06	34	LE-23	15						
	GR-19	20	LE-08	11						
Mean species										
Selected		97		66		70				84
Discarded	GR-24; GR-15; GR-03; GR-34		LE-06; LE-16; LE-12; LE-01		CO-09; CO-07; CO-15				LA-06; LA-03; PL-03	
Mean		3		34		30				16
L(N+P)	Experiment 3									
	GR-01	23	LE-11	68	CO-03	91			PL-03	76
	GR-05	22	LE-23	23					PL-01	
	GR-20	17								
	GR-25	14								
Mean species										
Selected		76		94		91				94
Discarded	GR-19; GR-15; GR-27; GR-36		LE-14; LE-01; LE-38; LE-21		CO-19; CO-05; CO-15				LA-06; GE-01; EU-01; RA-01	
Mean		24		6		9				6
L(N+P)	Experiment 4									
	GR-01	29	LE-26	53	CO-05	68			PL-03	27
	GR-02	27	LE-01	15					CA-02	21
	GR-04	12	LE-25	12					PA-01	10
									PL-02	10
Mean species										
Selected		68		80		68				84
Discarded	GR-11; GR-03; GR-05; GR-07		LE-11; LE-14; LE-21; LE-33		CO-19; CO-06				CA-01; PL-01; CR-01; LA-01;	
Mean		32		20		32				16

3-6). In all experiments, the greater biomass of GR species increased competition, thus decreasing biomass and species numbers in the LE, CO, LA, CA and 'miscellaneous' families.

The effect of phosphorus addition is dependent on prevailing environmental conditions. Under more favourable conditions, there is greater microbial activity and species in the GR family are promoted, while under less favorable conditions the LE species perform better. Leguminous (LE) species were favoured by P-addition in all experiments. Tilsdale et al. (1985) reported that phosphorus is crucial to root development in legumes, since it promotes the development nitrogen-fixing bacterial nodules. In experiments 1 and 3, phosphorus addition also increased the production of GR

Table 11. Species code comprised in the higher cluster group and those in the discarded group over the years of evaluation in the H(N+P) treatment in the locations of the Mediterranean environments.

Treatment	Gramineae Species codes	%	Leguminous Species codes	%	Composites Species codes	%	Labiates Species codes	%	Miscellaneous Species codes	%
H(N+P)					Experiment 1					
	GR-19	67	LE-08	37	CO-05	65	LA-07	56	SC-01	94
	GR-01	8	LE-33	48	CO-16	27	LA-06	38		
	GR-21	12								
Mean species Selected		87		85		92		94		94
Discarded species	GR-09; GR-13; GR-22; GR-04		LE-19; LE-34; LE-23; LE-18		CO-08; CO-04		LA-03		PL-01; CA-02; RU-02; BO-01	
Mean		13		15		8		6		6
H(N+P)					Experiment 2					
	GR-01	45	LE-11	28	CO-09	57			LA-03	44
	GR-06	22	LE-10	20	CO-19	22			PL-02	46
	GR-11	21	LE-23	14						
Mean species			LE-07	11						
Selected		88		73		79				90
Discarded species	GR-03; GR-21; GR-05; GR-09		LE-14; LE-16; LE-26; LE-08		CO-07; CO-02; CO-05; CO-06				PL-03; LA-06; PL-01; CY-01	
Mean		12		27		21				10
H(N+P)					Experiment 3					
	GR-06	25	LE-23	37	CO-02	46			PL-02	41
	GR-05	21	LE-11	48	CO-19	25			PL-01	28
	GR-01	19	LE-33	11					PL-03	15
	GR-19	19								
Mean species Selected		84		85		71				84
Discarded species	GR-02; GR-34; GR-15; GR-25		LE-14; LE-25; LE-34; LE-19		CO-15; CO-05				LA-06; LI-08; RU-02; RA-02;	
Mean		13		15		29				16
H(N+P)					Experiment 4					
	GR-01	28	LE-26	64	CO-09	57			CA-11	23
	GR-03	17	LE-25	15	CO-19	22			RU-02	20
	GR-02	13							RU-03	19
	GR-06	13							PL-02	9
Mean species Selected		71		79		79				71
Discarded species	GR-07; GR-19; GR-05; GR-04;		LE-33; LE-21; LE-14; LE-19		CO-07; CO-02; CO-05; CO-06				CA-01; PL-03; LA-01; PA-01;	
Mean		29		21		21				29

species. These sites are characterized by a higher aridity index, resulting in greater microbial activity. As a consequence more nitrogen is available, favouring GR species. In the drier sites (experiments 2 and 4), lower microbial activity results in reduced nitrogen availability (Caradus 1980; Kemp & Blair 1994). Under such conditions, only LE species (which contain N-fixing bacterial nodules) benefit from phosphorus addition, and in doing so outcompete other species. In general, P-addition reduced the productivity of species in the CO, LA, CA and 'miscellaneous' families.

The combined nitrogen and phosphorus fertilizer treatments resulted in increased productivity of species in all families. Floristic composition was largely unaffected, however. Unlike the N and P treatments, the N+P treatments did not appear to increase competition amongst species, since GR and LE families did not increase substantially. Indeed, the L(N+P) treatment promoted a floristic development similar to that of the controls in most experiments. The H(N+P) treatment promoted to some extent the development of the LA, CA and 'miscellaneous' families, but floristic composition and structure remained similar to the control plots.

The combined (N+P) fertilizer treatments improved the agronomic fertility of the pasturelands, increasing productivity while reducing the effect of competition among botanical families and species within families. These treatments were able to sustain a higher microbial activity than the control, while at the same time increasing nitrogen uptake by making phosphorus available to soil microbes. In slightly acidic soils, a combined N+P fertilizer optimizes soil fertility while also increasing the availability of other limiting soil nutrients (Keen 1987; Miller & Reetz 1995; Rohweder & Albrecht 1995). Higher levels of fertilizer (the H(N+P) treatment) reduced the productivity and species abundance in the LA and 'miscellaneous' families (Table 10). However, the overall effect of the H(N+P) treatment was to increase pastureland productivity while promoting long-term sustainability and floristic composition of the native pastureland ecosystem (Table 11).

Conclusions

These results highlight the wide range of biomass production and floral composition of pasturelands in southern Italy. The fertilizer treatments affected biomass production, but the nature and degree of this effect was dependent on prevailing environmental conditions. Nitrogen addition generally favoured species in the GR family, which competitively suppressed species in the LA, CO, CA and 'miscellaneous' families. By contrast, phosphorus addition favoured leguminous species (LE family). The effect on other families was dependent on climatic conditions. The GR family was favoured in less arid environments, where P-addition promoted microbial activity. In more arid environments, only leguminous species were favoured by phosphorus addition. Combined nitrogen and phosphorus fertilization improved the agronomic fertility of the pasturelands, resulting in greater exploitation of mineral nutrients in the topsoil. Significantly, higher levels of fertilizer (the H(N+P) treatment) promoted biomass production without compromising the floristic composition of native pasturelands.

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APPENDIX

Codes of botanical family (two capital letters) and species (two digits hyphenated to family code) of herbs classified in the experiments.

Boraginaceae (BO-nn)
BO-01 Symphytum officinale L.
BO-02 Borago officinalis L.

Caryophyllaceae (CA-nn)
CA-01 Cerastium manticum L.
CA-02 Silene saxifraga L.
CA-11 Silene italica Pers.

Campanulaceae (CP-nn)
CP-01 Campanula garganica Ten.

Compositae (CO-nn)
CO-02 Senecio delphinifolius Vahl
CO-03 Senecio vulgaris L.
CO-04 Carlina corymbosa L.
CO-05 Cirsium spinosissimum Scop.
CO-06 Cirsium syriacum Gaertn.
CO-07 Cirsium polyanthemum Spr.
CO-08 Cardopatium corymbosum Pers.
CO-09 Cichorium intybus L.
CO-15 Tragopogon porrifolius L.
CO-16 Centaurea subtilis Bert.
CO-19 Sonchus oleraceus L.

Cruciferae (CR-nn)
CR-01 Diplotaxis erucoides DC.

Cyperaceae (CY-nn)
CY-01 Carex polygama Schk.

Dipsacaceae (DI-nn)
DI-01 Knautia arvensis Coult.

Euphorbiaceae (EU-nn)
EU-01 Euphorbia dendroides L.

Geraniaceae (GE-nn)
GE-01 Erodium gruinum LÆHr.

Graminaceae (GR-nn)
GR-01 Dactylis glomerata L
GR-02 Hordeum bulbosum L.
GR-03 Aegilops ovata L.
GR-04 Bromus fasciculatus Presl.
GR-05 Agropyrum repens P.B.
GR-06 Lolium rigidum Gaud.
GR-07 Nardus stricta L.
GR-10 Agrostis alba L.
GR-11 Imperata cylindrica P.B.
GR-12 Lolium multiflorum Lam.
GR-13 Lolium perenne L.
GR-15 Brachypodium distachyum P.B.
GR-16 Lygeum spartum L.

GR-18 Phleum echinatum Host
GR-19 Stipa barbata Desf.
GR-21 Festuca rubra L.
GR-22 Festuca caerulescens Desf.
GR-23 Psilurus incurvatus Schinz et Thell.
GR-24 Trisetum flavescens P.B.
GR-25 Secale cereale L.
GR-26 Phleum subulatum Asch. et Gr.
GR-27 Bromus sterilis L.
GR-28 Eleusine indica Gaertn.
GR-29 Triticum villosum Schult.
GR-30 Avena fatua L.
GR-33 Phleum paniculatum Huds.
GR-34 Vulpia incrassata Parl.
GR-35 Alopecurus mysuroides Huds.
Gr-36 Agropyrum junceum P.B.

Leguminosae (LE-nn)
LE-01 Trifolium repens L.
LE-04 Trifolium speciosum W.
LE-06 Trifolium leucanthum M.B.
LE-07 Trifolium maritimum Huds.
LE-08 Trifolium incarnatum L.
LE-09 Trifolium suffocatum L.
LE-10 Trifolium subterraneum L.
LE-11 Trifolium resupinatum L.
LE-12 Hippocrepis multisiliquosa L.
LE-14 Medicago orbicularis All.
LE-16 Medicago disciformis DC.
LE-17 Lotus corniculatus L.
LE-18 Lotus pusillus Medic.
LE-19 Lotus coniugatus L.
LE-21 Vicia sativa L.
LE-22 Melilotus sulcata Desf
LE-23 Medicago italica Steud.
LE-24 Medicago ciliaris Krock
LE-25 Trifolium squarrosum L.
LE-26 Trifolium arvense L.
LE-27 Ononis spinosa L.
LE-28 Trifolium montanum L.
LE-33 Trifolium alexandrinum L.
LE-34 Medicago secundiflora Dur.
LE-35 Onobrychis viciaefolia Scop.
LE-37 Trifolium pratense L.
LE-38 Vicia faba L.

Labiatae (LA-nn)
LA-01 Galeopsis tetrahit L.
LA-02 Lavandula stoechas L.
LA-03 Lamium flexuosum Ten.
LA-05 Thymus capitatus H. et LK.
LA-06 Marrubium alysson L.
LA-07 Dracocephalum ruyschiana L.

Liliaceae (LI-nn)
LI-08 Tragopogon porrifolius L.

Plantaginaceae (PL-nn)
PL-01 Plantago lanceolata L.
PL-02 Plantago maritima L.
PL-03 Plantago montana Lam.

Polygonaceae (PO-nn)
PO-01 Polygonum aviculare L.

Ranunculaceae (RA-nn)
RA-01 Anemone apennina L.
RA-02 Ranunculus acer L.

Rubiaceae (RU-nn)
RU-02 Galium aparine L.
RU-03 Galium verum L.
RU-04 Galium tricorne Stok.

Scrophulariaceae (SC-nn)
SC-01 Melampyrum arvense L.

Umbellifereae (UM-nn)
UM-01 Daucus carota L.