Phosphorus fertilization of forage and pasture legumes in Morocco: Comparison of station and on-farm trials

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Abstract

As animals are an intrinsic part of Middle Eastern agriculture, the provision of adequate forage is a critical concern. In dryland Mediterranean conditions, phosphate (P) fertilization has been shown to be essential for cereals, depending on soil P test levels, but less research emphasis has been given to pasture and forages. Responses have been shown to vary with the forage species as well as the cultivar. Few field studies have assessed the comparative responses of common forage species and varieties to P fertilization in dryland Mediterranean conditions, while P studies of native pasture medics are rare. Thus, in the rainfed central zone of Morocco, we evaluated P fertilizer responses of 9 legume species from 4 forage crops (vetch, medic, pea, and lathyrus) on 3 experimental stations/sites with varying available soil P levels. We also examined the effect of added P on growth of native re-generated medic pasture for 8 seasons in on-farm trials on a range of soil types in the region and variable annual rainfall (200-550 mm). Responses from the experimental stations varied with the legume species and cultivars and the site, largely because of differences in P level. While the field trials showed variable responses to applied P with the year's rainfall and the site, most trials showed that P application rates as low as 20 kg ha^{-1} were adequate to produce significant yield increases and also increased the proportion of legumes in the plant biomass. At higher P application rates, forage quality is likely to be improved as well. Both sets of trials created a strong basis for promoting P fertilization of forages, whether applied to either crop in the normal cereal/forage rotation practiced in countries of the Mediterranean region. An adequate soil analysis program is fundamental to providing a basis for rational fertilizer use.

Key Words: *P fertilizer use, forage fertilization, available soil P, forage legumes, dryland cropping, Morocco*

التسميد الفسفوري للبقوليات العلفية والرعوية بالمغرب؛مقارنة نتائج محطة التجارب بمحطة المزارعين

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ملخص

يعتبر الأكل كمصدر للتغذية في بلدان البحر الأبيض المتوسط أحد العوائق الأساسية لتنمية قطاع الماشية. ومن أجل الرفع من مستوى الإنتاجية للأعلاف وخاصة البقوليات العلفية، قمنا بتجربة إعطاء كميات متفاوتة من التسميد الفوسفاطي لتسعة أصناف من البقوليات العلفية تحت ثلاثة أنواع من التربة ذات مستوى فسفوري متفاوت. دامت هذه التجربة لمدة سنتين تحت الظروف المطرية لسهل الشاوية بالمغرب الأقصى. وبرهنت النتائج على أن إعطاء كميات السماد الفسفوري إلى حدود 20 كغ في الهكتار حسنت من الإنتاجية وجودة الأعلاف البقولية. وكان تجاوب الأصناف والأنواع المدروسة. وبالتالي تبين الدراسة على أهمية إمكانية الرفع للإنتاجية للبقوليات سواء كانت رعوية أو علفية.

الكلمات المفتاح: التسميد الفوسفاطي، تسميد الأعلاف، البقوليات العلفية، الزراعات البعلية، الأنظمة الزراعية بالمغرب

Résumé

Le cheptel est une composante intrinsèque des systèmes de production de la zone pluviale du Moyen Orient. L'approvisionnement en ressources fourragères reste une contrainte principale dans l'alimentation animale. Dans les zones pluviales arides et semi arides, la fertilisation phosphatée a été démontrée efficace pour l'amélioration des rendements des céréales. Cependant, peu de recherches ont été conduites sur les cultures fourragères. La réponse des légumineuses à la fertilisation phosphatée a été variable en fonction des espèces et variétés. Peu d'études aux champs sur les légumineuses fourragères et pastorales ont été conduites pour déterminer les effets des engrais phosphatés sous les conditions arides et semi arides méditerranéennes. Nous avons évalué la réponse de neuf variétés appartenant à quatre légumineuses fourragères (Vesce, Lathyrus, Medics et pois fourrager) aux différents apports de P_2O_5 sous trois types de sols ayant différents niveaux de fertilité phosphatée. Nous avons aussi évalué au champ les effets des apports croissants en P_2O_5 sur la croissance des Medics spontanée sur une période de huit ans. La réponse des légumineuses aux P_2O_5 sur les trois types de sols des stations expérimentales a été variable selon l'espèce, la variété et le site. Mais des quantités allant jusqu'à 20Kg/ha de P_2O_5 ont amélioré les rendements et la qualité de la plupart des variétés des légumineuses étudiées. Les deux essais conduits sur les légumineuses fourragères et pastorales ont montré les effets positifs de la fertilisation phosphatée que se soit sur les céréales ou les légumineuses dans le cadre de rotation sous les conditions climatiques des pays méditerranéens. Une analyse du sol est adéquate pour déterminer la quantité de P_2O_5 à apporter par type d'espèces et de cultures.

Mots clefs : *Utilisation des engrais phosphatés, fertilisation des fourrages, disponibilité du P_2O_5 dans le sol, légumineuses fourragères, cultures pluviales, agriculture Maroc.*

Introduction

The Mediterranean region is reputed to be the center of origin of settled agriculture and has been cultivated for millennia (White, 1970). Most of the world's major crops such as cereals and legumes have evolved there. The climate of the region is typically Mediterranean, with a cool, moist season (fall, winter, early spring), where rainfed cropping is possible, followed by a hot dry season where cropping is only possible with irrigation (Kassam, 1981). The farming system in such a climatic area has traditionally centered around rainfed cereal cropping (Cooper *et al.*, 1987), mainly with breadwheat (*Triticum aestivum*), and barley (*Hordeum vulgare*) grown in rotation with fallow or food legumes and forage legumes such as vetch (*Vicia sativa*), i.e., chickpea (*Cicer arietinum*) and lentil (*Lens culinaris*) and medic (*Medicago* spp), or in some cases, as a continuous cereal crop.

As is characteristic of Mediterranean-type climates, there is considerable inter-annual and within-season variability (Kassam, 1981). Mean annual rainfall is relatively low, generally ranging from 200-600 mm. Crop production is generally constrained by drought; indeed in most years, there is invariably a degree of terminal drought. While irrigation has always been practised in arid areas where river water is available, e.g., Euphrates/Tigris and Nile Rivers, increasingly supplemental irrigation based on groundwater sources, is encroaching, in traditional rainfed areas in order to compensate for moisture deficiencies and to stabilize crop yields (Oweis *et al.*, 1998).

Irrespective of whether the system is rainfed or irrigated, animal production, mainly sheep (*Ovis aries*) and to a lesser extent goats (*Capris hircus*), in drier areas, is integrated with crop production (Cooper *et al.*, 1987). Thus, food production for human consumption and feed provision for the burgeoning animal population are twins concerns in the Mediterranean region. Shortage of livestock feed has put pressure on rangelands, which are commonly overgrazed, with consequent soil degradation (FAO, 1987).

The only alternative to rangeland for animal feed has to come from the cropped sector (Lazarev, 2004), with straw, either as cut or stubble grazed being the traditional livestock feed. Increasingly, emphasis has been placed on feed legumes (pasture or forage) to improve both the quantity and quality of animal feed (Abd El-Moneim *et al.*, 1988). A possible solution approach has been to develop indigenous forage species or introduce new species for grazing and stored feed (Thompson *et al.*, 1992).

While a broad overview of Mediterranean forages has been given by Abd El-Moneim and Ryan (2004), the role of fertilizers and nutrients has been limited to the effects of N and organic matter in cereal-legume trials with respect to organic matter and soil aggregation (Masri and Ryan, 2006) and N responses (Ryan *et al.*, 2002). By comparison, despite the importance of soil and fertilizer phosphorus (P) for cropping under Mediterranean conditions (Matar *et al.*, 1992), there have been relatively few reports of P on forage legumes from the Mediterranean region (Materon and Ryan, 1995; 1996). One field study on a shallow soil in Morocco (Ryan *et al.*, 1992) showed that some vetch cultivars responded to applied P but others did not. Similarly, none of the medics studied responded to P. However, Derkaoui *et al.* (2004) showed that in a greenhouse study of 8 medic biotypes on a very low-P soil (2 mg kg^{-1} Olsen P), the responses in growth ranged from 2 to 5-fold. Research in Australia under dryland conditions suggests a strong influence of P on forage yields and crop quality as reflected by P concentration in the seeds (Bolland, 1985; Bolland and Baker, 1989). In assessing crop response to P or any other nutrient, it is important that varietal differential response be considered and that varieties are assessed for adaptation in the target environment (Jones, 1990).

In the dryland zone of central Morocco, a major thrust of the research at the Dryland Research Center in Settat was to expand forage legume production (Ryan *et al.*, 2007). Given the importance of P, which is normally applied to cereals in rotation with legumes, there is a need to assess, under controlled experimental station conditions, the P-responsiveness of potentially adoptable vetch and medic varieties and to extend the findings to on-farm conditions. Thus, we examined the growth response to applied P of several forage legumes at three experimental stations/sites for one growing season and P fertilization of native medic pasture on 40 farmers' fields over the period of 8 years.

Materials and methods

Two phases are presented in this work in accordance with our objectives. The main trial concerned the responses to P application of 9 annual forage legumes species grown in the various agricultural experimental stations, followed by the second phase that was conducted on native medic fertilization on farmers' fields.

On-station fertilizer trials

Three experimental sites with different levels of soil available P (0.5 M $NaHCO_3$) were chosen for this study. A survey of chemical properties in experiment stations in the central Morocco zone (Ryan *et al.*, 1990) indicated that all three sites were calcareous, with varying amounts of free calcium carbonate, and consequently a pH of around 8. The main differences were in available P, texture, soil depth, and organic matter (OM), and cropping history. The stations were:

1. Mnasra : low available soil P, 7 mg kg^{-1}; 3 % OM; brown shallow loamy clay (Petrocalcic Palexeroll) without cropping for the previous 10 years and used only as pasture;
2. Jmaat Riah : medium soil P, 10 mg kg^{-1}; 1.5% OM; red moderately deep clay soil (Palexerollic Chromoxerert) used for wheat and barley production; and
3. Sidi El-Aydi: high soil P, 17 mg kg^{-1}; 2.5% OM; deep dark clay soil (Vertic Chromoxerert) mainly used for wheat production.

The three sites were from the Chaouia plain near Settat in the central region of Morocco, an area important for its cereal production in Morocco. The average annual rainfall for the region is 350 mm. The fields used for the study had wheat, barley or "weedy" fallow pasture as the previous crops, the latter type of fallow being unique to North Africa.

The forage crops used for the experiment were vetch, lathyrus (*Lathyrus sp*), medic (*Medicago sp*), and pea (*Pisum sativum*), i.e. *V. narbonensis, P. sativum* and *L. cicera, L. sativus, L. ochrus, V. ervilia, V. sativa, V. villosa,* and a mixture of four species of medics (*M. truncatula, M. polymorpha, M. littoralis, M. scutellata*). The land was prepared at the beginning of the cropping season in early November, 1996, by deep plowing, followed by a disc-harrow. Planting was done by "Wintersteiger" experimentation seed drill with a row spacing of 30 cm. The seeding rates were as follows:, *V. narbonesis, L. ochrus,* L. *cicera, L.sativus, and P. sativum,* 90 kg ha^{-1}; V. *sativa* and V. *villosa,* 70 kg ha-^{1}; and V. *ervilia,* 40 kg ha^{-1}. The *Medicago* spp were seeded at 30 kg ha^{-1}. Weeding was done manually at emergence, plant spreading, and flowering and at maturing stages. Fertilizer application at planting, other than P, was limited to 20 kg N ha^{-1} and 80 kg K ha^{-1} for all the fields..

Phosphorus (P) was applied at 3 levels in the main plots on each set of the species, i.e. no fertilizer as control; 20 kg P ha^{-1} (medium) and 40 kg P ha^{-1} (high) application rates that are recommended to farmers. The experimental arrangement applied here was a split-plot design, with species as the experimental unit (sub-plot). At each site, the treatments were replicated three times.

The data collected were total biological yield and seed production. The statistical analysis involved using the Three-Way Analysis of Variance and T-test for means comparison (SAS, 1985).

Rainfall

Rainfall conditions during the 1995-96 growing season exceeded the annual average of the region, but its distribution was skewed. In fact, more than 270 mm were received from September to December, with 231.8 mm during the month of December alone, which affected crop establishment and soil characteristics. After this abundant rainfall, a severe mid-season drought, with above-average seasonal temperatures which persisted from mid February to late April, delayed crop growth and hardened the topsoil. However, the planted forage crops in the trials did not suffer seriously from the drought mainly because of their early rooting and drought-tolerance traits. In addition, weeding helped reduce soil moisture loss and take advantage of the late-season rains. Plant development was advanced by one week after the enhanced temperatures. The early-maturing species (less than 110 days) were: *P. sativum, L. ochrus,* and *V. ervilia,* whereas, *V. villosa,* and *V. sativa* were late-maturity types (125 days).

On-farm fertilization trials

These trials were conducted for 8 years, i.e. 1988-89 until the 1995-96 growing season, on a total of 40 farms. These farms were selected from different areas of Settat province. Soil types varied from sandy coastal soils, to deep clay soils, to shallow stony calcareous soils. Similarly, available nutrients and soil chemical properties showed a wide range of variation (Abdel Monem *et al.*, 1990). Available soil P content was generally low (< 8 mg kg^{-1}) reflecting limited use of P fertilizer. Land use was dominated by cropping systems that are characterized by barley/pasture rotations with low fertilizer inputs. As is typical of Morocco's dryland zone, rainfall varied widely between years and within years. The mean rainfall (mm) for the 8 years was 360 (1988/89), 300 (1989/90), 160 (1990/91), 394 (1992/93), 216 (1993/94), 120 (1994/95), and 463 (1995/96).

Each year, 4 to 9 farmers' fields that still have enough seeds of native medics in the soil as a seed bank were selected for P fertilization trials. The idea was to show farmers that the use of fertilizer (triplesuperphosphate, 45% P_2O_5) that would be expected to benefit the legumes in the pasture by increasing both forage and *in situ* seed production, and also benefit barley in the rotation by the residual effects of both the legume-fixed N in the soil and the residual P from the previous year. The treatments applied involved one fertilizer rate (20 kg P ha^{-1}) and a control without P fertilization. The data collected during the first year included: botanical composition, forage yields of legumes, and seed yield of native medics. Given the variability between the experimental sites, years, and farm practices, we used the modified stability analysis approach to determine the effects of P fertilization on forage and grain yields by recommendation domains.

Results

Herbage yield response: On station

Herbage yields varied with the site, being a function of soil type (especially depth) and rainfall. Thus, Sidi El-Aydi gave the highest dry matter (DM) yields for all species, as opposed to those of Mnasra or Jmaat Riah. Grain yield followed the same pattern. Soil P application rates positively affected biological yields of most species (Fig 1). However, yield response to P application was related to the soil P statues: grain yield from P application was more pronounced in the low-P soil and the medium-P soil, with respective biomass yield increases of 40.8 and 1.4 t ha^{-1}, and 1.0 and 1.5 t ha^{-1}. There was no difference between P rates and the control for the high-P soil (Sidi El-Aydi). There was a species –by- soil type and fertilizer interactions; species responded more to increasing P in the Jmaat Riah and Mnasra soils, whereas in the black Vertisol of Sidi El-Aydi, it only responded positively when 40 kg P ha^{-1} was applied (Table 1).

Table 1. Total herbage dry matter yield[1] of forage legumes with phosphorus fertilization at three experiment stations in central Morocco.

Genus/ species	Phosphorus application rate (kg ha^{-1}) Mnasra 0	20	40	Jmaat Riah 0	20	40	Sidi El-Aydi 0	20	40
	t h^{-1}								
Vicia									
Narbonensis	5.0^{c}	6.0^{b}	6.6^{a}	5.1^{c}	6.3^{b}	8.4^{a}	7.4^{c}	7.6^{b}	8.1^{a}
Sativa	5.0^{b}	5.4^{ab}	6.1^{a}	7.3^{a}	6.9^{a}	7.5^{a}	7.8^{a}	7.5^{a}	7.6^{a}
Villosa	4.2^{c}	5.4^{b}	6.1^{a}	6.5^{a}	7.2^{ab}	7.5^{a}	6.7^{b}	7.2^{b}	7.8^{a}
Ervilia	4.2^{c}	6.1^{b}	6.7^{a}	4.2^{b}	7.5^{a}	7.8^{a}	6.8^{b}	7.0^{b}	8.0^{a}
Lathyrus									
Ochrus	3.8^{b}	4.2^{b}	5.5^{a}	4.6^{b}	5.6^{b}	6.2^{a}	5.3^{ab}	5.9^{a}	4.9^{b}
Cicera	4.3^{b}	4.9^{a}	5.1^{a}	4.9^{c}	5.8^{b}	6.7^{a}	6.8^{a}	7.2^{a}	6.9^{a}
Sativus	3.3^{b}	4.2^{a}	4.0^{a}	5.6^{a}	5.7^{a}	5.9^{a}	5.9^{a}	5.7^{a}	6.1^{a}
Pisum sativum	3.0^{c}	3.5^{b}	4.2^{a}	3.5^{c}	4.5^{a}	4.0^{b}	6.3^{a}	5.6^{b}	5.9^{ab}
Medicago	3.2^{b}	3.5^{b}	4.2^{a}	3.5^{b}	4.5^{a}	4.0^{ab}	4.3^{b}	4.6^{b}	5.9^{a}

Within the same soil type numbers followed by different letters are significantly different

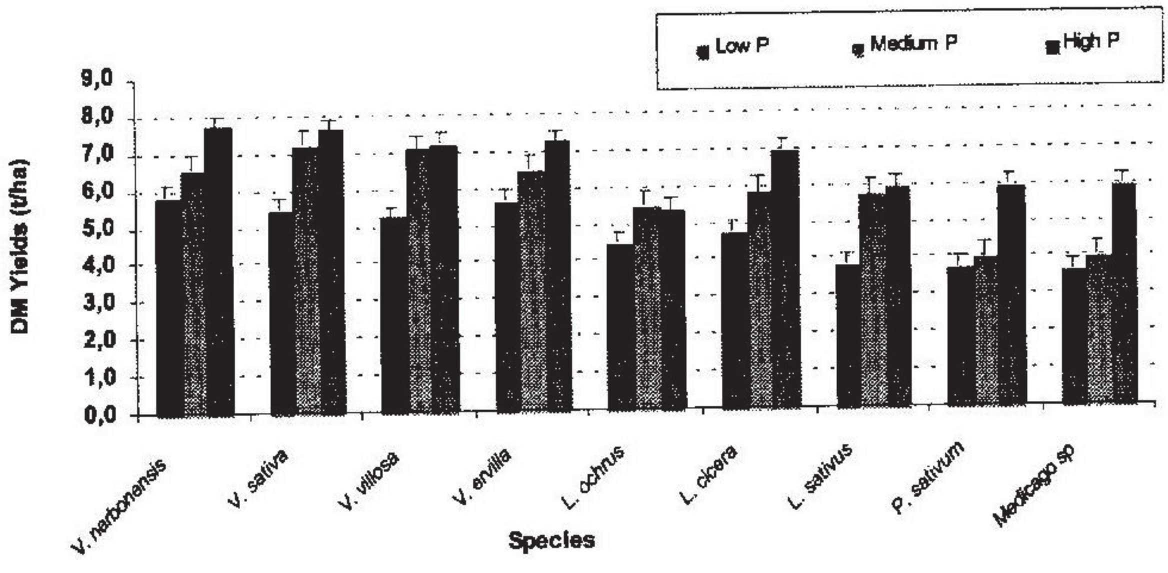

Figure 1. DM Yield response of nine fodder legumes to P application under three soil types of Chaouia plains

There was a differential response in terms of species. Accordingly, V. *sativa* responded only in the low-P soil (Mnasra), but not in the others. *Lathyrus ochrus* also reached its maximum yield in the high-P Sidi El-Aydi soil when 40 kg P ha^{-1} was applied. In other sites, it was still responding to increased P fertilizer in the same way as *V. ervilia*, thus showing their need for a higher level of available P to sustain maximum yield. *L. sativus* showed a plateau response to P fertilization in the soils. These results demonstrate that forage legume species have different needs for P, particularly when considering different soil types. Soil test P calibration and fertilizer P management need to be more carefully studied in crop rotations that involve these different forage legumes species.

Seed yield responses: On -station

Seed yield responses of these forage legumes correlated positively with increasing P fertilizers for all species and in each soil type (Table 2). More yield gains were obtained in the low-P and medium-P soil than in the high-P soil (Fig 2). The relationship between crop responses and soil P level was illustrated by the fact that as soil P level increased (from Mnasra, to Jmaat Riah, and to Sidi El-Aydi), the relative response to P decreased in terms of grain yield (e.g., relative responses of 72, 29, and 9% for the 20 kg P level and 95, 65, and 24 for the 40 kg P ha^{-1} level.

Highest seed yields were reached in the high-P soil of Sidi El- Aydi for all species. Significant positive effects of P fertilizer on seed yields were registered for all species in the study. Indeed, in the low-P soil (Mnasra), the increase from P application varied from 30 to 180%. These values varied from 11 to 17% for the medium-P soil and from 28 to 44% for the high-P soil. Over all sites, relative seed yield gains varied from 14 to 30% for the 20 kg P/ha rate and from 25 to 90% for the 40 kg P ha^{-1} rate.

Table 2. Total grain yield[1] of forage legumes with phosphorus fertilization at three experiment stations in central Morocco.

Genus/ species	Phosphorus application rate (kg ha^{-1})								
	Mnasra			Jmaat Riah			Sidi El-Aydi		
	0	20	40	0	20	40	0	20	40
	t ha^{-1}								
Vicia									
Narbonensis	0.8^{b}	1.3^{ab}	1.6^{a}	1.9^{c}	2.1^{b}	2.5^{a}	2.4^{b}	2.6^{ab}	2.8^{a}
Sativa	1.0^{b}	1.3^{ab}	1.5^{a}	1.3^{b}	1.5^{ab}	1.8^{a}	1.8^{a}	2.1^{a}	2.0^{a}
Villosa	0.7^{c}	1.3^{b}	1.7^{a}	0.7^{c}	1.2^{b}	1.9^{a}	1.8^{ab}	1.^{5b}	2.1^{a}
Ervilia	0.9^{b}	1.6^{ab}	1.8^{a} @	1.3^{b}	1.6^{ab}	1.8^{a}	2.1^{b}	2.3^{ab}	2.4^{a}
Lathyrus									
Ochrus	0.6^{b}	1.2^{a}	1.3^{a}	0.7^{b}	0.9^{b}	1.7^{a}	1.6^{b}	1.8^{ab}	2.1^{a}
Cicera	1.5^{c}	2.1^{b}	2.9^{a}	1.8^{c}	2.5^{b}	2.9^{a}	2.^{8b}	2.9^{b}	3.6^{a}
Sativus	1.0^{b}	1.5^{a}	1.7^{a}	1.4^{b}	1.6^{b}	2.1^{a}	1.8^{b}	2.4^{a}	2.5^{a}
Pisum sativum	0.7^{b}	1.3^{a}	1.4^{a}	0.8^{b}	1.0^{ab}	1.1^{a}	1.7^{b}	1.7^{b}	2.3^{a}
Medicago	0.5^{c}	1.1^{b}	1.4^{a}	1.4^{b}	1.9^{a}	1.5^{b}	1.3^{a}	1.3^{a}	1.5^{a}

[1]Within the same soil type, numbers followed by different letters are significantly different

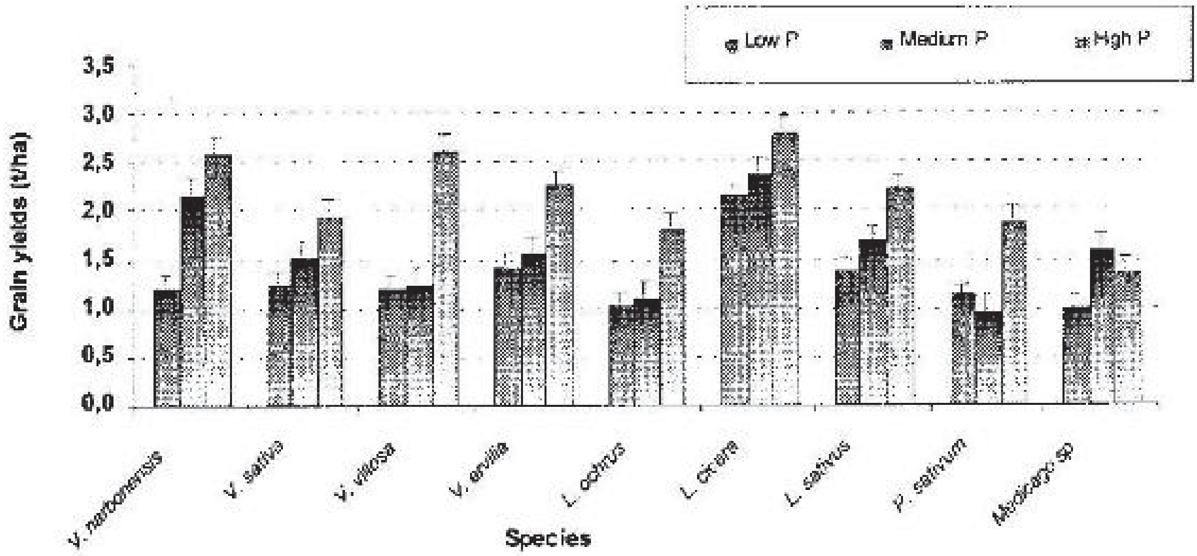

Figure 2 : Grain yield response of nine fodder legumes to P application under three soil types of Chaouia plains

There was significant genus x P fertilizer rate x site interaction. For example, *Vicia* reached its maximum yield in the high-soil P of Sidi El-Aydi when 20 kg P/ha was applied, but in other sites it was still responding favourably to increasing rates of P fertilizers. Low P in the soil significantly limited seed production of *V. narbonensis, V. villosa, L. ochrus, L. sativus*, and *P. sativum*. Both *P. sativum* and medics produced very limited amounts of seed in each soil type, even when P fertilizer was applied.

The mean growth responses to applied P in terms of grain yield averaged over the three sites (Table 3) clearly show the differences between the various species. Interestingly, as the P application doubled from 20 to 40 kg ha^{-1}, the mean response of all species also doubled from 25% top 51%.

Table 3. Average percentage grain yield gain in response to application rates of nine forage legume species grown in three soil types having different available phosphorus levels.

Genus/Species	Applied P, kg ha^{-1} 20	40
	-----%-----	
V. narbonensis	18	35
V. sativa	14	29
V. villosa	30	90
V. ervilia	29	43
L. ochrus	30	70
L. cicera	25	55
L. sativus	29	50
P. sativum	30	60
Medicago spp.	17	25
Mean	25	51
LSD (5%)	11	15

Botanical composition: On-farm

Botanical composition responded positively to applied P application, particularly in good rainfall years. The overall average (40 farms x 15 samples) of the legumes dry matter contribution to the biomass total DM harvested each spring (March) varied from 24% for the control to 54% in the superphosphate-treated pastures. This difference of 20% between the two treatments had a great impact on soil-fixed N, herbage yield and quality, on seed yield and quality, and on the yield of the subsequent barley crop.

Herbage dry matter yield: On-farm

Dry matter yields, when averaged over both treatments (control vs 20 kg P ha^{-1} fertilized), gave what is termed the "the environment index". Such indices, which represent the overall average production by site, varied from 15 to 14 Mg dry matter biomass ha^{-1}. Each environment index is a synthesis of the management packages, the growth conditions of native medics, and the dominance of kind of medic species on this farm. When the index is low, it means unfavourable production and management conditions prevail for native medics, while a high index implies favourable production and management conditions for native medics.

This high variability is the result of differences in soil type (Stitou, 1985) and added fertility in terms of fertilizers used. Soils on which trials were established that and had less than 5 mg kg^{-1} P were distributed as follow: 21.3%, Calcixerolls; 64%, Vertisols; 4%, Xerochrepts; 5.7% sandy soils (Psamments) and 4.3% others. Differences between rainfall years (150 to 550 mm/year) and pasture management were also major factors. Given the high variability that is obtained in these kinds of trials, the use of modified stability analysis allows us to distinguish between response or recommendation domains.

The responses of dry matter biomass yield to increased environmental index were linear at this stage and did not reach a production plateau. The maximum yields obtained in high conditions for the control and P-fertilized pastures were 1.4 and 17.5 tonnes (t) DM ha^{-1}, respectively. These results therefore show the high effects of applying only 20 kg P ha^{-1} that is obtained on the improvement of feed production and quality.

Native medics seed yield: On farm

The same analysis made for DM production applies for native medics. The environment index varied from 0.01 to 2.75 t ha^{-1}. The seed increase response to the environment index was linear, showing the potential for improvement that might be realized under more favourable conditions by applying more P fertilizer, since the main percentage increase of the nine species was 25% for the 20 kg P rate and 51% for the 40 kg P ha^{-1}rate. Under a high index, the P-fertilized pastures produced 4 tonnes of pods, whereas, the farmers' practices produced only 1.4 t ha^{-1}. These results demonstrate the possible impact that will result from transferring all research results in the area of seed production at the farm level in order to increase and promote some new seed varieties or to protect and maintain *in situ* the present native genetic biodiversity of palatable species.

Discussion

The herbage and grain yield data from the three agricultural experiment stations in central Morocco's dryland agriculture zone of medium rainfall, as well as on 8-year dataset of on-farm trials in the same zone, conclusively show the benefits of P fertilization for forage legumes. Notwithstanding differences between the environments of the stations themselves, the available soil test data from the stations suggests significant growth responses with levels of P up to at level 10 mg kg^{-1} the level that occurred in the second station (Jmaat Riah). Even at the highest P level, some crops responded to P. While soil P levels tend to be higher on experiment stations (Ryan *et al.*, 1990) than on farmer's fields in Morocco (Abdel Monem *et al.*, 1990), they are likely to represent the P fertility levels encountered in most farmers' fields.

Thus, one could reasonably expect a high probability of grain and biomass of forage legumes to P fertilizer. As P has a residual effect for the succeeding crop (Anderson and Lachlam, 1981; Matar *et al.*, 1992), the benefits of fertilization would pertain to both crops in the rotation, i.e., cereals or legumes, or indeed weedy fallow. Regardless of which crop is actually fertilized, it is important to consider the benefit of fertilization in terms of the rotation as a whole (Jones, 1990), or cycles of the cereal/legume rotation.

While the overall mean relative response to the two P application rates were higher for grain than total biomass yields, the most interesting feature of the station trial was the differential responses of the genera and species to applied P. This field trial confirmed such P response variability show by Materon and Ryan (1995) with a range of medic species under greenhouse conditions. In addition, it showed species differences for the vetch and lathyrus. This differential genetic response to P fertilization has been commonly observed with annual pasture species, including legumes (Ozanne *et al.*, 1969); this reflects the internal P requirements for the species concerned. Studies by Bölland (1985) showed that high seed P concentration increases the effectiveness of P fertilizers so that less fertilizer was required to produce the same yield as P concentration in the seed increase.

The positive responses to P fertilizer of the various forage legumes evaluated here raises broader issues of the viability of using such legumes in Morocco, or indeed in the Mediterranean region in general. While pea is rarely cultivated as a forage legume, and then only in Morocco, the prospects for adoption of the other species are mixed. There was considerable interest in the promotion of medic as a self-regenerating pasture forage in the Mediterranean zone in the 1980's, i.e. the "ley farming" system that originated in Australia. However, despite positive responses to rhizobial inoculation and P fertilizer in greenhouse (Materon and Ryan, 1995) and field (Materon and Ryan, 1996; Ryan *et al.*, 2002;Thompson *et al.*, 1992) studies, and as observed in the current P responses both on-station and in farmers' fields, efforts at promoting medic at farm level have failed (Christiansen et al., 2000).

The non-adoption was attributed to technical difficulties in harvesting medic seed, overgrazing that prevents seed-regeneration, and small fragmented farms do not allow for any area of land being set aside for medic posture of the expense of a cereal crop. Intended as a replacement for fallow, medic did not complete with alternative crops, and remained a pasture weed in farmer's perception and of questionable economic attractiveness (Nordblom *et al.*, 1994).

In contrast to medics, the prospects for the positive effects of P fertilization clearly shown in this study to have an impact on vetch production as an animal feed in the region are much brighter. The various studies conducted in Syria (Jones, 1990; Jones and Singh, 2000) and Cyprus (Papastylianou, 1993) indicate that vetch is a suitable alternative to fallow and has advantage in terms of overall feed production and water-use efficiency. Of the vetches, Narbon vetch appeared to have more potential than common vetch or other species of vetch (Jones and Singh 2000) or Lathyrus. Despite the biomass yields of commonly used Lathyrus species in this study, *L . ochrus, L. cicera*, and *L. sativum*, the problem with the genus is an anti-nutritional factor ("lathyrism" caused by a toxin B-ODAP) when eaten in large quantities by livestock (Abd El-Monem and Ryan, 2004). Nevertheless, research is currently focused on breeding and selection of varieties of Lathyrus with low levels of the neurotoxin.

In conclusion, this on-station and on-farm research in Morocco's medium rainfall zone clearly showed the importance of fertilization for a range of forage legume species; the benefit is particularly evident where levels of available soil P are relatively low, i.e. <10 mg P kg^{-1}. Differential responses were evident between genera and with species, i.e. vetch and Lathyrus. The promotion of P fertilization for forage legumes has to be done within the context of overall adaptation of these species in dryland areas of the Mediterranean. A side-benefit of such legumes is a buildup of organic matter and total soil N (Masri and Ryan, 2006; Ryan *et al.*, 2002). Based on these considerations, technology transfer efforts should focus on vetch rather than medics, Lathyrus or pea, the latter which is only grown as a forage in Morocco. In view of the greater adaptability and resilience of underground vetch (Christiansen *et al.*, 1996; Abd El-Moneim and Ryan, 2004), future P research should focus on this type of crop.

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