Alfalfa Production as a Function of Soil Extractable Phosphorus in the Semi-arid Pampas

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This research provides insight into soil nutrient limitations for the main alfalfa producing soils of the semi-arid Pampas. Comparisons of critical extractable soil phosphorus (P) values were made among four common soil testing procedures.

The semi-arid Pampas region of Argentina is commonly characterized as having nitrogen (N), P, and sulfur (S) deficiency as a result of low native soil fertility and wind erosion. In reality, information on annual and pasture crop responses to nutrients is scarce, variable, and sometimes contradictory. Variability in crop response to P fertilization might be explained by differences in total and/or available soil P. Results from a climosequence analysis describe similar total P levels among agricultural soils in the region (Prüeß et al., 1992). Thus, variations in crop response must at least be partially explained by differences in available soil P.

Several factors can modify soil P availability. These include: phosphate sorption by amorphous iron (Fe) and aluminum (Al) oxides, as well as precipitation of calcium phosphate in the presence of excess carbonate. Variability in crop response to P could also be attributed to other nutrient deficiencies. For example, in the eastern part of La Pampa Province, S deficiency is known to reduce alfalfa dry matter responses to P and N fertilization (Bariggi et al., 1975; Díaz-Zorita and Fernández-Canigia, 1998). Zinc (Zn) and copper (Cu) are also known yield-limiting factors for this region of Argentina (González and Buschiazzo, 1996).

The Bray Kurtz 1 procedure is commonly used for the evaluation of available P for annual and pasture crops, but is less effective for soils with free calcium carbonate contents. The Olsen extraction procedure is thought to be more reliable for high pH soils, while the Mehlich 3 procedure is widely promoted for its multi-nutrient extraction capability and reduced soil analysis costs. The objective of this study was to determine the relationship between four different P extraction procedures and alfalfa dry matter production under greenhouse conditions.

Surface horizons from 10 Entic Haplustoll soils were selected to obtain a range of available P levels. Main soil properties are presented in **Table 1**. Available soil P was determined using the Bray Kurtz 1 (Beech and Leach, 1989), Olsen (Olsen and Sommers, 1982), Kelowna (Buschiazzo et al., 1999), and Mehlich 3 (Mehlich, 1984) procedures (**Table 2**). Four fertilization treatments (**Table 3**) were added to 1,400 cm^3 pots arranged in a randomized complete block (RCB)

Table 1. Mean physicochemical properties of the test soils from the semi-arid Pampas, Argentina.

Soil	Clay	Silt	Sand	SOM	Nt	Water pH	Alo	Feo
	- - - - - - - - - - - -	- - - - -	% - - - - -	- - - - - -			- - - mg/kg	- - -
A	5.8	7.0	87.2	1.5	0.08	6.6	1,105	565
B	11.5	18.0	70.5	1.1	0.06	8.1	1,360	557
C	11.8	29.2	59.0	2.8	0.14	6.5	930	1,032
D	10.7	35.6	53.7	2.2	0.10	8.0	1,540	560
E	9.3	43.5	47.2	5.2	0.27	7.2	1,535	597
F	18.5	34.4	47.1	2.7	0.12	6.2	1,255	1,187
G	30.5	45.8	24.3	5.2	0.27	5.7	1,705	1,372
H	10.0	9.3	80.7	1.2	0.06	5.8	1,155	607
I	10.0	13.3	76.7	2.5	0.11	5.8	1,135	675
J	12.2	19.1	68.7	2.1	0.10	5.9	730	900

SOM = soil organic matter, Nt = total nitrogen, Alo = aluminum amorphous oxides; Feo = iron amorphous oxides

design with three replicates. Pots were planted to rhizobium-inoculated alfalfa. Aerial dry matter (DM) was measured at 108 and 166 days after seeding. Total P, S, potassium (K), Ca, magnesium (Mg), Fe, Cu, and Zn were determined in composite samples from each treatment, sampling date, and test soil. Results of DM production were analyzed by analysis of variance (ANOVA) procedures and the Tukey mean comparison test. The mean crop response in each soil was related to soil test P as determined by each of the four extraction procedures using a linear-segmented model.

Table 2. Soil extractable P levels for four different procedures on 10 soils from the semi-arid Pampas, Argentina.

Soil	Bray Kurtz 1	Olsen	Kelowna	Mehlich 3
	- - - - - - - - - - - -	- - - mg/kg	- - -	- - - - - - - - - - - -
A	9.5	–	–	16.9
B	3.6	–	11.5	–
C	24.2	8.6	26.9	26.5
D	9.3	2.6	10.8	13.5
E	10.6	3.7	14.2	15.9
F	37.3	18.6	37.6	35.2
G	67.2	61.5	86.1	56.8
H	9.2	3.1	10.2	14.7
I	29.0	11.6	40.2	28.0
J	5.9	6.2	13.7	11.3

Results

Alfalfa dry matter production varied between 1.17 and 7.05 g/pot per sampling date, showing significant interactions between soil-type and fertilization treatment. The effect of sampling date was independent of soil-type and fertilization treatment. Thus, treatment effects were analyzed separately for each soil using the average of the two sampling dates.

Treatments produced significant differences ($p=0.05$) in dry matter production in soils A, B, C, E, H, and J compared to the control (**Table 4**). Soils A and H had a significant dry matter response to P fertilization alone. The complete minus P treatment (CF - P) increased dry matter production relative to the control in soils A, C, E, and H. Only soils A and B produced less dry matter than the complete treatment (CF) under the CF - P treatment. Together, these results suggest that most soils showed relevant changes in dry matter production after fertilization with nutrients other than P.

The absence of a response to P and other nutrients in the soils D, F, G, and I is explained by high extractable P and soil organic matter contents, and low sand contents (**Table 1**). Thus, under the experimental conditions, these soils were able to provide higher nutrient supplies through mineralization. Differences in DM production were partially explained by differences in tissue P levels [DM (g/pot) = $0.95 + 4.45\,P_{tv} + 3.22\,P_{tv}^2$, $r^2 = 0.575$, $p=0.05$].

Tissue analysis of the non-fertilized control treatments showed

Table 3. Fertilization treatments and levels of applied nutrients.

Treatment	P_2O_5	K_2O	S	N	B	Cu
	Nutrients					
	- - - - - - - -	- - - - - - -	- - kg/ha-	- - - - - -	- - - - - -	- - -
Control	–	–	–	–	–	–
Complete fertilization (CF)	79	52.4	26.2	22.5	0.6	1.5
Complete without P (CF - P)	–	52.4	26.2	24.0	0.6	1.5
P fertilization (PF)	79	52.4	–	–	–	–

Table 4. Effects of four fertilizer treatments on alfalfa dry matter production (average of two sampling dates) using 10 semi-arid Pampas soils.

Soil	Treatment			
	Control	PF	CF - P	CF
	g/pot			
A	1.54 c	2.57 b	2.40 b	3.56 a
B	2.04 b	2.36 b	2.32 b	4.09 a
C	3.06 b	3.31 b	4.30 a	4.49 a
D	2.22	2.94	2.69	3.82
E	3.99 c	4.82 ab	4.43 bc	5.71 a
F	3.53	3.89	4.47	4.16
G	4.78	4.90	4.71	4.76
H	2.74 b	3.96 a	3.50 a	4.50 a
I	3.22	3.23	4.01	4.68
J	2.53 c	3.25 bc	3.33 ab	4.23 a

Different letters indicate significant differences between treatments (p=0.05).

S contents below the critical level of 0.22% in most soils, which suggests that S, and not P, could be the limiting nutrient for optimal alfalfa production. Several authors have obtained similar results after fertilizing alfalfa and pastures in field studies in the area (Díaz-Zorita and Fernández-Canigia, 1998). In soils A, B, E, F, and H, the tissue Zn contents in control pots were higher than those in treatments fertilized with P alone, suggesting that P fertilization under low Zn availability could induce Zn deficiency and lower crop yield. Tissue Mg contents were also below the critical level for optimum alfalfa dry matter production, which may be due to cation competition between K and Mg in soils with high native K levels.

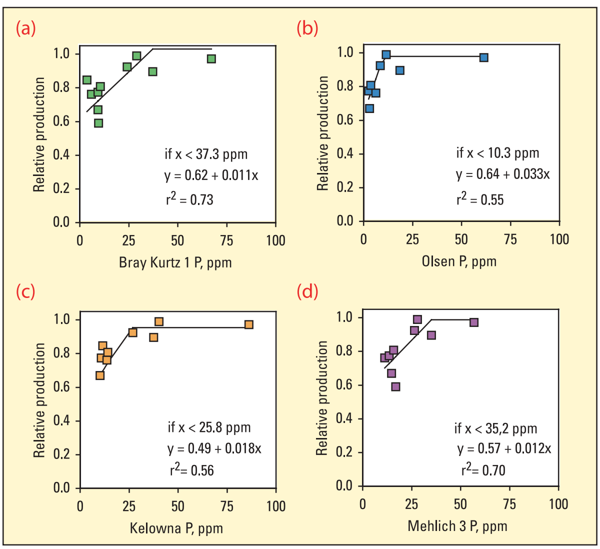
Phosphorus concentration in alfalfa tissues were significantly correlated with extractable soil P levels no matter which extraction procedure was used.

Relative DM production was related to extractable soil P contents when expressed either as the ratio between the control and PF treatment, or the ratio between the CF - P and CF treatments (**Figure 1**).

Despite large variation in the measured values, strong linear relationships existed between the four extracting procedures (**Table 5**). Since no differences existed between the duration, intensity, or soil:extractant solution ratio used in the extraction procedures, the lower extractable soil P values obtained with the Olsen procedure is explained by the lower reactivity of the extraction solution, $NaHCO_3$, compared to the extraction solutions used in the Bray Kurtz 1 or Mehlich 3 procedures.

The critical extractable soil P content, based on the Bray Kurtz 1 procedure, was greater than those values suggested in field studies (Peaslee, 1978; Culot, 1986). This is likely an artifact common to pot studies wherein small soil volumes allow full exploration by plant roots and complete exhaustion of available soil nutrients. As a result, the critical levels for alfalfa dry matter response to P fertilization should not be considered conclusive.

Figure 1. Relationship between relative alfalfa dry matter production, as the ratio CF -P/CF, and soil P levels extracted according to (a) Bray Kurtz 1, (b) Olsen, (c) Kelowna, and (d) Mehlich 3 procedures.



Conclusions

Alfalfa dry matter production in soils of the semi-arid Pampas region, under greenhouse growing conditions, depends on extractable soil P and the availability of other nutrients such as S, Mg, and Zn. The response of alfalfa to P fertilization could be partially explained by the extractable soil P contents determined by the Bray Kurtz 1, Olsen, Kelowna, or Mehlich 3 procedures. The critical

Table 5. Linear relationship between soil extractable P levels extracted by four different procedures.

$P_{Olsen} = -7.2 + 0.90\ P_{Bray\ Kurtz\ 1}$	$P_{Bray\ Kurtz\ 1} = 9.7 + 0.99\ P_{Olsen}$	$r^2 = 0.89$
$P_{Kelowna} = 2.2 + 1.18\ P_{Bray\ Kurtz\ 1}$	$P_{Bray\ Kurtz\ 1} = -0.9 + 0.81\ P_{Kelowna}$	$r^2 = 0.96$
$P_{Mehlich\ III} = 8.0 + 0.73\ P_{Bray\ Kurtz\ 1}$	$P_{Bray\ Kurtz\ 1} = -10.5 + 1.35\ P_{Mehlich\ III}$	$r^2 = 0.98$
$P_{Kelowna} = 11.8 + 1.25\ P_{Olsen}$	$P_{Olsen} = -7.8 + 0.74\ P_{Kelowna}$	$r^2 = 0.93$
$P_{Mehlich\ III} = 9.6 + 1.44\ P_{Olsen}$	$P_{Olsen} = -4.3 + 0.58\ P_{Mehlich\ III}$	$r^2 = 0.84$
$P_{Mehlich\ III} = 6.27 + 0.66\ P_{Kelowna}$	$P_{Kelowna} = -5.4 + 1.32\ P_{Mehlich\ III}$	$r^2 = 0.87$

extractable soil P content for maximum alfalfa dry matter production depended upon the extraction procedure. Further field study is required to estimate critical P levels for fertilization recommendations in this region. In such studies, it is suggested to apply adequate levels of S, Mg, and Zn, since these nutrients were observed to be limiting factors for optimal alfalfa growth. BC

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References

Bariggi, C., N. Romero, and G. Schenkel. 1975.. EEA INTA Anguil. Proyecto Alfalfa-FAO-INTA 71/584.

Beech, D.F. and G.J. Leach. 1989. Australian Journal of Experimental Agriculture 29: 655-662.

Buschiazzo, D.E., S. Aimar, and T. Zobeck. 1999. Soil Sci. 164: 133-138.

Culot, J.P. 1986. p. 81-117. *In* INTA (ed.), Investigación, Tecnología y Producción de Alfalfa. INTA, Buenos Aires. Argentina.

Díaz-Zorita, M. and M.V. Fernández-Canigia. 1998. Ciencia del Suelo 16: 103-106.

González, G.P. and D.E. Buschiazzo. 1996. *In* Actas XV Congreso Argentino de Ciencia del Suelo. Asociación Argentina de la Ciencia del Suelo (ed.), AACS. p. 179-180. Santa Rosa, LP. Argentina.

Mehlich, A. 1984. Commun. Soil Sci. Plant Anal. 15: 1409-1416.

Olsen, S.R. and L.E. Sommers. 1982. Phosphorus, p. 403-429. *In* A.L. Page, R.H. Miller, and D.R. Keeney (eds.), Methods of Soil Analysis, Part 2. Chemical and Microbiological Properties. ASA-SSAA, Madison, WI. USA.

Peaslee, D.E. 1978. Commun. Soil Sci. Plant Anal. 9:429-442.

Prüeß, A., D.E. Buschiazzo, E. Schlichting, and K. Stahr. 1992. Catena 19: 135-145.