J. Range Manage.
50:274–277

Post–burn recovery in the flooding Pampa: Impact of an invasive legume

PEDRO LATERRA

Author is adjunct professor, Cátedra de Ecología, Facultad de Ciencias Agrarias, Universidad Nacional de Mar del Plata (UNMdP)–EEA Balcarce, INTA. CC 276 (7620) Balcarce, Argentina.

Abstract

Winter burning of *Paspalum quadrifarium* Lam. stands ("pajonales") promotes colonization of denuded spaces by several alien species. *Lotus tenuis* Waldst et Kit. ("lotus"), a recent invader of the region, is able to reach very high densities between the resprouting bunches of the dominant species. Results of a removal experiment performed to evaluate the impact of natural establishment of lotus on post-burn colonization of pajonal stands are reported. Seedlings of lotus were removed shortly after their emergence between burned bunches of *P. quadrifarium*. Eighty days after burning, approximately 30% of the soil surface remained uncovered within removal plots, whereas canopy cover was complete within controls. Furthermore, final (137 days post-burn) total aboveground biomass was 2.7 times higher in control than in removal plots. Removal of lotus significantly (P<0.05) increased the cover of an annual native grass (*Phalaris angusta Nees,* ex Trin.) and the final biomass of an alien thistle (*Carduus acanthoides* L.). A spatial association analysis provided additional evidence about the negative impact of lotus on colonization success of *C. acanthoides*. Weed colonization may be reduced, if not prevented, by managing the colonization processes of other new and useful invaders.

Key Words: *Paspalum quadrifarium*, removal experiment, fire, colonization, weeds, *Lotus tenuis*, Argentina

Paspalum quadrifarium Lam. ("paja colorada", thereafter "paspalum") is a bunch grass (1.50 m tall) that, under low disturbance regimes, excludes other species and forms dense patchy stands locally called "pajonal". Pajonal stands were probably responsible for the physiognomy of an important portion of the pre-settlement flooding pampa (Argentina); 25 years ago, the pajonal still occupied 14,000 km^2 of that region (Vervoorst 1967, León 1991). An important but unmeasured area of remnant pajonal persist today, mainly restricted to non-arable soils.

Winter burning of pajonal stands increases cattle stocking rates, but also promotes important infestations of exotic weeds, particularly of thistles (Cauhépé 1990, Sacido et al. 1995). In mature pajonal stands (those with a tall and dense canopy), the basal area of paspalum is generally less than 30%. Therefore, winter burning creates open spaces for seedling recruitment (Laterra et al. 1994). Spear thistle (*Cirsium vulgare* (Savi.Ten.) welted thistle (*Carduus acanthoides* L.), and narrowleaf birdsfoot trefoil (*Lotus tenuis* Waldst et Kit, thereafter "lotus") are common exotic colonizers of such spaces. However, annually burned experimental plots with high lotus biomass, showed lower colonization by thistles than plots with low lotus biomass (Laterra et al. unpublished data). Thus, interference (competitive and/or non-competitive, Hall 1974) effects, like those reported between other fugitive species (e.g. Platt and Weis 1985) are likely between lotus and thistles, as well between lotus and other colonizer species. The potential ability of lotus to reduce thistle establishment in burned stands has a particular management relevance because the former species represents an exceptional forage resource for these legume-poor grasslands (Montes 1988), and because thistles are unpalatable weeds without forage value.

Lotus is a warm-season, perennial legume from Europe that became naturalized in the flooding pampa only a few decades ago (Montes 1988). In contrast, thistle abundance in the region was noted by several travellers in the early past century (Vervoorst 1967). Studies regarding invasions of rangelands by alien plants are generally focused on their impact on native species (e.g. Parsons 1972, Musil 1993, but see Sheley and Larson 1994). The lotus-thistles case represents an interesting opportunity to assess the impact of a new invader on the established alien flora.

Results of an experiment performed to evaluate the impact of lotus on the post-burn development of pajonal stands are reported. This study sought to quantify: (1) the effects of post–burn occupation of pajonal stands by lotus on colonization by thistles and other colonizer species, and (2) the effects of colonization by lotus on canopy recovery rate and biomass production between bunches of paspalum after burning. Additional evidence of the influence of lotus is provided by analysing the spatial association between the presence of adult plants of welted thistle and the abundance of lotus. This study focused on welted thistle because the results of the removal experiment suggested it was one of the species most affected by the presence of lotus, and because welted thistle is a serious pest species in burned pajonal stands.

Materials and Methods

Study Site

The study was carried out in a rangeland located at San Ignacio, 20 km south of Ayacucho, Argentina, in the southeastern

The author wish to thank G. Weingast for facilities to work in his field; F.Lattanzi and F.Buckley for assistance in the laboratory processing of samples, and Dr. F. Andrade and 3 anonymous reviewers for improving the manuscript. Financial support was provided by the UNMdP, project AGR 20/93.
Manuscript accepted 9 Jun. 96

part of the flooding pampa. This is a 58,000 km^2 region characterized by flat poorly drained soils having a general deficiency of available phosphorus, and a temperate climate with frequent winter-spring floods and summer droughts (León 1991). Median annual precipitation for Ayacucho is 1029 mm, and the precipitation during the experimental period (September–February 1993-1994) equaled the median amount of the past 10 year median (549 mm and 550.5 mm, respectively) (Ayacucho Agency of the Instituto Nacional de Tecnología Agropecuaria, unpublished).

The pajonal stands of San Ignacio occur as patches associated with slight topographic elevations. One patch of nearly 3 ha was selected for a long term experiment about fire effects on pajonal community structure. The present data were obtained from a 0.7 ha plot belonging to that experiment, selected according to its topographic, soil and physiognomic uniformities. The plot was burned in the early spring 1990 (11 October) and late winter 1992 (26 August) and was lightly grazed during each post–burn summer. This management caused lotus to become a codominant species of the pajonal stand, with an important seed bank of 2.2 viable seeds/cm^2 by the time of the second burning (Maceri et al., unpublished data).

Field Methods

The complete study sector was burned again with a backfire on 10 September 1993. At that time, adults of paspalum had a mean height of 45.6 cm (SE=0.2, N=28), the standing biomass had a mean dry weight of 118.2 g/m^2 (SE=5.2, N=16) which was 37% green (SE=0.9, N=16). Humidity content of green and senesced biomass was 85 and 61%, respectively. Wind speed during burning was less than 25 km/h, and air relative humidity was 37%. The mean maximum fire temperatures, estimated with Tempilsticks (R) (Big Three Industries, Inc. Hamilton Blvd, South Plainfield, N.J. 07080, USA) placed at the soil level between paspalum bunches, was 189°C (SE=7.2, N=19). Only the tiller bases of paspalum and crowns of lotus remained unburned; the inter–bunch spaces were completely denuded. Since previous studies at the same site showed that, unless grazed, fast post–burn regeneration of the pajonal canopy caused low establishment of paspalum and any other species (Laterra et al. 1993, 1994), the entire pajonal patch (3 ha) was grazed with 10 cows, during 3 discontinuous days, between December 1993, and January 1994.

Removal Experiment

One month after the fire (early spring), thirty 30 × 50 cm permanent plots were randomly placed between bunches within a 400 m^2 square area at the center of the pajonal patch, excluding a few sites occupied by 1 or more adult plants (established before the last fire) of lotus or any other species. Half of those plots were randomly assigned to a removal treatment while the rest were left intact. At this time, seedlings of lotus which had emerged after the fire had only 1 or 2 leaves; all of the lotus seedlings within the removal plots were cut at the soil level. Clipping of a new established cohort of lotus seedlings was performed at a similar growth stage 1 month later. Seedling density of lotus was estimated on vertical photographs of 4 additional 30 × 50 cm plots, randomly taken in the study area at the time of the first clipping.

Seedlings were clipped instead of uprooting to minimize soil disturbance. Eighty days after burning, at the beginning of summer, each plot was photographed vertically from a height of 1.50 m, and the plants were identified to species level. At this time, regrowth of paspalum bunches wasn´t extended over the plots. Canopy cover was estimated for each species using the photographs, by recording the length of intersections along 15 random transects totalling 3.25 m per plot. After 137 days post–burn (early summer), all aboveground biomass was harvested, oven dried and weighed.

Removal response coefficients (C) were calculated for each species, as:

$$C = (N_r - N_c) / N_r$$

where N_c is the mean biomass or cover of the target species in the control plots and N_r is the mean biomass or cover of the target species in the removal plots. Coefficient values from $-\infty$ to 1 represent increasing site preemption plus interference intensity experienced by the target species due to lotus. However, results of removal experiments may also be affected by indirect interactions (Aarsen and Epp 1990), and negative values of C can only be explained by them.

Statistical analysis of cover variables was accomplished using Student's t-test on untransformed data. Variance heterogeneity and/or lack of normality in biomass of some species could not be normalized through data transformations, so, they were analyzed using the Kruskal–Wallis's test.

Spatial association

In late summer (170 days post-burn), all adults of lotus and welted thistle were counted within 60 circular plots each 30 cm in diameter within the study sector. Half of the plots were randomly placed and the other half were centered on single adult plants of welted thistle growing among bunches of paspalum. The same procedure was repeated using 60 cm diameter plots, centered on the previous ones. The hypothesis of independence of plant density as a function of proximity to welted thistle, was examined using the Chi-square test.

Results and Discussion

No grass seedlings, a few thistle seedlings at cotyledonary stage, and many lotus seedlings were observed within the experimental plots at the first clipping date. Mean lotus seedling density was 34 seedling. dm^{-2} (SD=10.6, N=4) at the time of the first clipping. Clipping was not effective in completely excluding lotus from the plots since 80 days after burning this species had reestablished from both seeds germinated within plots and from plants growing immediately adjacent to the plots (Table 1). However, clipping the initial growth affected the recovery rate and species composition between bunches. Eighty days after burning, nearly 30% of soil remained uncovered within removal plots, whereas control plots were completely covered.

Removal of lotus enhanced the cover of all the species present at the first sampling date, as reflected by the positive and high

Table 1. **Canopy cover (means ± 1 S.D.) in the interspace between adult plants of *Paspalum quadrifarium* 80 days after burning for the *Lotus tenuis* removal and control treatments. Only species with mean relative canopy cover equal to or greater than 1% in any treatment are shown. C is the removal response coefficient (see text for explanation). P is the significance level of the Kruskal-Wallis test.**

Species	C	Canopy cover Removal	Canopy cover Control	P
		----- (%) ------		
Lotus tenuis	—	19 ± 9	91 ± 5	<0.001
Phalaris angusta	0.85	30 ± 16	4 ± 4	<0.001
Trifolium repens	0.75	9 ± 13	2 ± 4	0.027
Cirsium vulgare	0.83	5 ± 10	1 ± 2	0.571
Carduus acanthoides	0.91	2 ± 3	1 ± 1	0.086
Crepis capilaris l (Wall.)	0.95	2 ± 5	1 ± 1	0.272
Carduus nutans L.	1.00	1 ± 1	1 ± 1	0.165
C. vulgaris plus *C. acanthoides*	0.87	8 ± 9	1 ± 2	0.006
Total	—	68 ± 1	99± 1	<0.001

removal coefficients, suggesting an indiscriminated or diffuse interference effect of lotus between the principal colonizer species. However, this effect was significant only for the annual native grass *Phalaris angusta* Nees, ex Trin., for the exotic legume *Trifolium repens* L., and for the combined cover of the 2 most abundant thistles (both aliens), spear thistle and welted thistle. In contrast, the effect of lotus removal on the final biomass of the inter-bunch colonizers was less diffuse. Removal coefficients varied from welted thistle, the only species which showed a positive and significant treatment effect, to other species like *T. repens* which showed a negative but non-significant effect (Table 2). No pattern was found between removal coefficients and characteristics of target species like origin (native or exotics), taxon (monocots or dicots) or life history (annuals or perennials). The species that showed the most significant response in the first sampling, *P. angusta*, also showed positive but non-significant effects of removal treatment at the end of the experiment. Together with

Table 2. **Aboveground biomass of colonizing species (means ± 1 S.D.) in the interspace between adult plants of *Paspalum quadrifarium* 137 days after burning for the *Lotus tenuis* removal and control treatments. P is the significance level for the Student's t test, except for *Vulpia dertonensis*, *Phalaris angusta* and *Carduus acanthoides* L. where P is the significance level of the Kruskal-Wallis test. Biomass of species lower than 0.5 g/m² were pooled under the "other species" category. Total biomass includes all the species biomass plus non-identified plant residues. C is the removal response coefficient (see text for explanation).**

Species	C	Biomass Removal	Biomass Control	P
		------- (g/m^2) -------		
Lotus tenuis	—	26.0 ± 10.7	192.9 ± 72.9	<0.001
Phalaris angusta	0.43	20.1 ± 17.4	11.4 ± 17.7	0.218
Carduus acanthoides	0.85	10.7 ± 14.5	1.5 ± 1.5	0.046
Trifolium repens	-0.63	7.8 ± 9.3	12.7 ± 24.0	0.793
Stipa spp.[(1)]	0.25	4.8 ± 7.4	5.9 ± 6.7	0.675
Vulpia dertonensis	0.99	3.7 ± 12.7	0.1 ± 0.2	0.312
Paspalum quadrifarium	0.01	0.6 ± 1.0	0.6 ± 0.8	0.967
other species[(2)]	-0.80	3.5 ± 5.1	6.4 ± 7.1	0.255
Total	—	90.2 ± 32.7	242.6 ± 71.1	<0.001

[(1)] mostly *S. neesiana*, *S. philippii*, and *S. formicarum*
[(2)] mostly *Carex* spp., *Plantago lanceolata* and *Picris echioides*

Vulpia dertonensis (all.) Gola, an annual exotic grass, they have a winter-spring cycle and only senescent tissues of these species were present at the time of the final harvest (summer).

As was said above, the experimental design applied here did not provide control for indirect interaction effects, which could be influencing both the positive and negative results. Thus, indirect influences from herbivores or soil microflora (e.g. Bergelson 1990, Holt 1977), cannot be assessed.

Consistent with the above results, the natural variation in lotus abundance explained a significant portion of the spatial pattern of welted thistle, both at 30 and 60 cm scales (Chi-square=14.9; 1 d.f.; p<0.001, and Chi-square=14.4; 2 d.f.; p<0.001, respectively). For example, for plots of 30 cm in diameter, frequency of this thistle was 2.7 times lower than expected when there was more than 3 lotus plants within the same plot (Fig. 1).

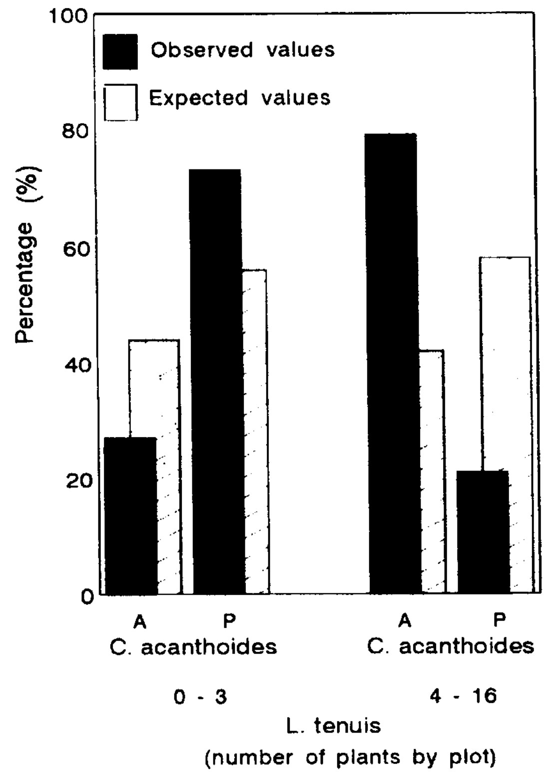

Fig. 1. **Percentages of 30 cm diameter plots in which *Carduus acanthoides* was absent (A) or present (P) (1 to 3 adult plants), when *Lotus tenuis* had different number of adult plants within the same plots. The expected values are the calculated percentage of plots according to the independence hypothesis between the spatial distribution of both species.**

Altering rates of resource supply is one of the most important effects of biological invasions at the ecosystem level (D'Antonio and Vitousek 1992). A reduction of 64% in the lotus contribution to final total biomass (from 79.3% in control plots to 28.9% in removal plots), reduced the final total biomass in a similar proportion (63%) (Table 2). Similar results were recently observed by Insausti, Soriano, and Quinos (unpublished data) in other grasslands of the flooding pampa (without *P. quadrifarium*), where the introduction of lotus after selective removal of all other broad-leaved herbs determined two–fold increments in leaf area index and biomass of the entire community. Thus, the rapid and complete covering of soil and/or the symbiotic nitrogen fixation by lotus, may have contributed to a greater resource uptake by the community, at least within the inter-bunch areas.

Like most legumes, lotus has high innate seed dormancy (Mujica and Rumi 1993), and thus the soil seed bank may be capable of persisting through long periods in which the habitat is occupied by a closed canopy cover. The heat from fire breaks innate seed dormancy of legumes by mechanical alteration of the seed-coat (Bradstock and Auld 1995), promoting massive germination of the buried seeds. Since both spear thistle and welted thistles do not form permanent seed banks (Soriano and Eilberg 1970, Roberts and Chancellor 1979, Klinhamer and De Jong 1993), their colonization of burned patches would mainly depend on immigration of seeds from previously disturbed patches, like it occurs with other ephemeral fugitives (e.g. Theaker et al. 1995). These life history differences suggest that seed production by thistles (annual or biennial life cycle) may have a faster post-burn decline than seed production by the perennial lotus. Thus, there may be an optimal fire frequency which could deplete or reduce the transient seed banks of thistles, while the seed bank of lotus is replenished or even increased. This burning frequency would cause dense establishment of lotus after fire, diminishing the opportunities for colonization by thistles from edge sources.

Conclusions

Colonization patterns of burned pajonal grasslands by lotus partially explained post-fire structure of the community. Increased abundance of this species reduced colonization by some thistles and annual grasses. These results illustrate that colonization of certain weeds may be reduced, if not prevented, by other new and useful invaders. Furthermore, colonization by lotus increased the plant biomass in the inter-bunch areas of the pajonal. Fire regime, as well as initial population structure of the principal colonizer species, may be important factors affecting the success of using selected invaders to manage other invaders.

Literature Cited

Aarsen, L.W. and G.A. Epp. 1990. Neighbour manipulations in natural vegetation: a review. Veg. Sci. 1:13–30.

Bergelson, J. 1990. Spatial patterning in plants: opposing effects of herbivory and competition. J. Ecol. 78:937–948.

Bradstock, R.A. and T.L. Auld. 1995. Soil temperatures during experimental bushfires in relation to fire intensity: consequences for legume germination and fire management in south–eastern Australia. J. Appl. Ecol. 32: 76–84.

Cauhépé, M.A. 1990. Manejo racional de paja colorada. Revista CREA (Argentina). 143:62–69.

D'Antonio, C.M. and P.M. Vitousek.1992. Biological invasions by exotic grasses, the grass/fire cycle, and global change. Ann. Rev. Ecol. Syst. 23:63–87.

Hall, R.L. 1974. Analysis of the nature of interference between plants of different species. I. Concepts and extension of the De Wit analysis to examine effects. Aust. J. Agr. Res. 25:739–747.

Holt, R.D. 1977. Predation, apparent competition and the structure of prey communities. Theor. Pop. Biol. 12:197–229.

Klinhamer, P.G.L. and T.J. De Jong. 1993. *Cirsium vulgare* (Savi) Ten. J. Ecol. 81:177–191.

Laterra, P., L. Ricci, P. Linares, A. Giaquinta, O. R. Vignolio, O.N. Fernández, and N.O. Maceira. 1993. Demografía de *Paspalum quadrifarium* frente a quemas inverno–primaverales en la Pampa Deprimida. Estado de avance., p. 131–138. *In*: C. Kunst, A. Sipowicz, N. Maceira, and S. Bravo de Mitre (eds), Ecología y Manejo de Fuego en Ecosistemas Naturales y Modificados. INTA, Santiago del Estero, Argentina.

Laterra, P., L. Ricci, O. Vignolio, and O.N. Fernández. 1994. Efectos del fuego y del pastoreo sobre la regeneración por semillas de *Paspalum quadrifarium* en la Pampa Deprimida, Argentina. Ecología Austral (Argentina) 4: 101–109.

León, R.J.C. 1991. Vegetation. *In*: Soriano, A. Río de la Plata Grasslands. *In*: R.T. Coupland (ed.). Natural Grasslands. Elsevier. Amsterdam.

Montes, L. 1988. Lotus tenuis. Revista Argentina de Producción Animal 8:367–376.

Mujica, M.M. and C.P. Rumi. 1993. Dinámica del estado de dureza de semillas de *Lotus tenuis* (Waldst et Kit) obtenidas del suelo en respuesta a un régimen de baja temperatura. Revista Facultad de Agronomla, La Plata (Argentina) 69:64-75.

Musil, C.F. 1993. Effect of invasive Australian acacias on the regeneration and nutrient chemistry of South African lowland fynbos. J. Appl. Ecol. 30:361-372.

Parsons, J. 1972. Spread of African pasture grasses to the American Tropics. J. Range Manage. 25:12-17.

Platt, W.J. and I.M. Weis. 1985. An experimental study of competition among fugitive prairie plants. Ecol. 66:708-720.

Roberts, H.A and R.J. Chancellor. 1979. Periodicity of seedling emergence and achene survival in some species of *Carduus*, *Cirsium* and *Onopordum*. J. Appl. Ecol. 16:641-648.

Sacido, M., V. Juan, M. Cauhépé, and L. Monterroso. 1995. Variaciones en la composición florística de un pastizal por efecto de quema, siembra de *Lotus tenuis* y controles químicos. Actas del XII Congreso Latinoamericano de Malezas, pp. 339-345. Montevideo, Uruguay.

Sheley, R.L. and L.L. Larson. 1994. Comparative growth and interference between cheatgrass and yellow starthistle seedlings. J. Range Manage. 47:470–474.

Soriano, A. and B.A. de Eilberg. 1970. Efecto de los cambios de profundidad de las semillas en el suelo, sobre las posibilidades de perpetuación de las malezas: *Ammi majus*, *Carduus acanthoides Cynara cardunculus*. Revista de Investigaciones Agropecuarias (INTA, Buenos Aires). Serie II 7:335–345.

Theaker, A.J., N.D. Boatman, and R.J. Froud-Williams. 1995. Variation in *Bromus sterilis* on farmland: evidence for the origin of field infestations. J. Appl. Ecol. 32:47–55.

Vervoorst, F.B. 1967. Las comunidades vegetales de la Depresión del Salado (Provincia de Buenos Aires). La Vegetación de la República Argentina. Serie Fitogeográfica 7, Instituto Nacional de Tecnología Agropecuaria. Buenos Aires, 262 pp.