Journal of Applied Horticulture, 11(1): 68-72, January-June, 2009

Growth interference of invasive Russian knapweed on "valcatorce INTA" onion

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Abstract

Russian knapweed is an invasive creeping perennial herb which affects crops by competition and allelopathy. Herbicides available for use in onion are not able to control Russian knapweed in a crop context. Conversely, recommended products for Russian knapweed are not selective for the crop. The aims of this work were to study Russian knapweed biomass production and propagation for a range of increasing densities in an experimental onion culture and to characterize the productive response of onion plants under these conditions. A partial additive experiment was carried out to study Russian knapweed interference (variable density, 0-64 ramet m^{-2}) on onion transplants (constant density, 40 pl m^{-2}) under greenhouse conditions in Viedma, Argentina (40º 03' S; 62º 48' O). Although no differences among treatments were found for weed final aboveground biomass, low density treatments (0, 2 ramet m^{-2}) were lower than 64 ramet m^{-2} for belowground biomass. Final weed density was proportional to initial conditions. For onion, total (-54%) and commercial bulb yield (- 56 %) were reduced by weed competition with $\geq$ 32 ramet m^{-2}. While size 3 bulbs (50-70 mm eq. diam.) were less represented at weed densities higher than 16 ramets m^{-2}, size 4 ones (70-90 mm eq. diam.) were not present in this condition. For *A. repens*, traits such as the rate of vegetative propagation, high competitive ability, mainly belowground, and high propagule pressure support its high invasive potential.

Key words: *Acroptilon repens*, *Allium cepa*, plant competition, partial additive experiment, plant invasion, irrigated agriculture.

Introduction

As a consequence of weed interference, vegetable yield and quality are subjected to severe losses in most irrigated areas in Argentina. Instead of rational management programs, weed control is normally done by herbicide application in a clearly reactive approach.

There are several irrigated valleys in southern Argentina whose areas are mostly dedicated to fruit and vegetable production for external markets. The Lower Valley of Rio Negro (LVRN), in particular, is located at the southeast of the Rio Negro province, near the Negro river outlet, at 40º S. It comprises 18,500 hectares of irrigated lands with a high value irrigation infrastructure of both concrete lined and unlined channels and also an efficient drainage system. There are almost 500 properties among 30-120 hectares each.

The invasive weed, Russian knapweed (*Acroptilon repens* L.), is increasing in incidence at the LVRN. While 2,000 hectares were directly and indirectly affected by 1980 (Dall Armellina and Iglesias, 1984) almost 50% of the properties reported patches of different size (10 m^2-100 hectares) in 2005. The affected area was actually estimated as 6,000 hectares approximately (Bezic *et al.*, 2005).

Russian knapweed is a creeping perennial herb which affects crops by competition and allelopathy (Watson, 1980; Whitson, 1987; Dall Armellina and Zimdahl, 1988; Gajardo *et al.*, 2004). It reproduces vegetatively by sprouting from roots. Each new ramet forms an early season rosette by the end of August which elongates in September, the time at which onion must be transplanted. The first flowers appear in November (Bezic *et al.*, 2005). Clonal populations of Russian knapweed may be 30-100 ramets m^{-2} in density and 40-60 cm in height, dense enough to be a strong competitor for any vegetable crop (Kearney *et al.*, 1960; Whitson, 1987; Panter, 1991).

Onion (*Allium cepa* L.) is the 3rd place vegetable crop in the LVRN with 500-1500 hectares annually sowed (Pozzo Ardizzi *et al.*, 2005). The species is considered a poor competitor against weeds because of its slow initial growth associated to few narrow and erect foliage leaves. If remain uncontrolled, weeds can reduce onion yield by 36-96 % (Khan *et al.*, 2003; Williams *et al.*, 2005).

Herbicides available for use in onion are not able to control Russian knapweed in a crop context. Conversely, recommended products for Russian knapweed are not selective for the crop.

The aims of this work were to study Russian knapweed biomass production and propagation for a range of increasing densities in an experimental onion culture and to characterize the productive response of onion plants under these conditions.

Materials and methods

Site and experimental methods: The experiment was carried out in a plastic covered 120 m^2 greenhouse, located at the Universidad Nacional del Comahue (CURZA) campus in Viedma, Río Negro province, Argentina (40º 03' S; 62º 48' O). All lateral windows remained open over the entire experimental period (26 October, 2004-20 March, 2005) in order to avoid excessive heating during summer. Twenty one 0.49 m^2 (0.70 m by 0.70 m) wooden boxes (35 cm deep), internally lined with a 200 microns black polyethylene sheet were used. Each box was filled with sandy-loam soil (OM 3 %; SAR 1.9) free of Russian knapweed propagule. The soil was nutrient enriched with 0.1 kg m^{-3} of 15-15-15 (N:P:K) at the beginning of the experiment. All boxes were separated 20 cm from the soil line by placing them on wooden blocks and the bottom of each one was perforated for drainage purposes.

Plant material: Several clonal plants of Russian knapweed were obtained by vegetative propagation of sprouting root pieces which were selected for the presence of one visible bud preformed in the original habitat. This plant material was collected in winter 2004 from a unique population colonizing an irrigated field. They were maintained under refrigeration at 5 ºC in plastic bags until September 15, 04 when they were individually placed in 368 cm^3 plastic pots (64 cm^2) to induce sprouting. Additionally, late onion cv. Valcatorce INTA transplants were produced in an experimental nursery until the two true leaves stage when they were transplanted in a regular 10 by 13 cm grid over the entire box surface (20 transplants per box; 408,000 plant ha^{-1}) on 26 October, 2004.

Experimental design: A partial additive experimental design was applied to study Russian knapweed interference (variable density) on onion transplants (constant density) under greenhouse conditions. The boxes were arranged in a complete randomized block design (*n*=3) with 7 treatments for *A. repens* density (AR): AR_0 (crop check without weeds); AR_2 (2 ramet m^{-2}); AR_4 (4 ramet m^{-2}); AR_8 (8 ramet m^{-2}); AR_{16} (16 ramet m^{-2}); AR_{32} (32 ramet m^{-2}): AR_{64} (64 ramet m^{-2}). Both species were transplanted the same day and they coexisted for a period of 145 days until onion harvest. The variables evaluated for onion plants included i) total and commercial fresh bulb yield (kg m^{-2}), ii) non commercial bulb proportion by size (bulbs <35 mm diameter) in terms of biomass and total number percentages, iii) onion plant survival (percentage of dead plants) and iv) bulb size distribution by commercial categories. Weed variables observed were: i) ramet density at harvest (final density, ramet m^{-2}), ii) above and belowground biomass at harvest (g DW m^{-2}), iii) vegetative propagation rate (VPR, final ramet number/ initial ramet number). Dry biomass was obtained by desiccation of fresh samples in an electrical oven at 65 ºC for 72 h.

Data analysis: While biomass data were logarithmically transformed (natural log, ln) to achieve homoscedasticity and normality, percentages were transformed by the usual arcsine transformation p' = arcsin(SQRT(p)), where p is the proportion. Data were subjected to ANOVA and the multiple comparison test SNK was applied. The LSD test was also employed in specific cases.

Results

Weed growth and propagation: As season was in progress new ramets were formed by sprouting from roots. This increased the box weed density for every treatment. The statistical analysis revealed that AR_2 and AR_4 were lower in final weed density in comparison with AR_{32} and AR_{64}. Intermediate treatments were intermediate in response and no differences were detected in relation to the previous reports on this aspects(Table 1).

Vegetative propagation rate (VPR, number of final ramets / number of initial ramets) was decreasing with initial density increase (Fig. 1). The highest VPR was calculated as 12.3 for AR_2 and the lowest as 2.6 for AR_{64}.

No differences among weed densities were observed for aboveground weed biomass at harvest (P = 0.13). The average value was calculated in 1.06 ± 0.11 ton DW ha^{-1} (Table 1).

The less conservative LSD test, however, indicated significant differences between AR_2 and AR_{32}, AR_{64}. Same results were obtained for the aboveground biomass in elongated plants (rosettes excluded) as shown in Table 1, were AR_2 plots evidence a biomass lower than AR_{32} and AR_{64}, which in turn were not different between them. Intermediate densities also showed an intermediate response.

Elongated ramet rate or proportion (elongated ramets/ total ramets) was the same among treatments, comprising the 62.8% of the complete ramet population. The mean elongated plant height was 34.4 cm and no differences among treatments were observed (Table 1).

Belowground biomass increased with the initial plant density in a direct proportional way. Differences among treatments were observed for AR_2 and AR_4 with respect to AR_{64}. Intermediate densities also showed an intermediate response (Table 1).

Onion bulb yield: As initial weed density increased, a decreasing tendency was observed for both total and commercial yield (Fig. 2). Bulb production was not reduced under low weed density in AR_2 (p>0.05). In this case the reference values were calculated

Table 1. Growth parameters of *Acroptilon repens* for initial densities of 0-64 ramets m^{-2} in onion transplanting

Initial density (ramet m^{-2})	Final density (ramet m^{-2})	Rate of elongated plants (%)	Total aboveground biomass (g DW m^{-2})	Aboveground biomass of elongated plants (g DW m^{-2})	Elongated plants height (cm $plant^{-1}$)	Belowground biomass (g DW m^{-2})
2	25.2(6.7)a	76.7(6.2)	57.9(20.1)a	53.6(19.5)a	31.28(1.80)	25.8(8.8)a
4	47.6(6.7)a	60.5(5.9)	103.4(5.0)ab	101.3(11.6)ab	32.62(1.36)	47.1(7.1)a
8	87.8(30.9)ab	64.8(6.9)	117.5(34.9)ab	96.4(29.1)ab	36.57(1.48)	74.6(28.0)ab
16	81.0(3.6)ab	55.2(3.3)	96.6(7.3)ab	82.0(5.3)ab	38.00(3.39)	77.3(8.4)ab
32	164.6(52.8)b	61.6(4.7)	118.1(27.2)b	102.7(25.4)b	32.60(2.12)	105.6(44.4)ab
64	172.1(14.9)b	58.2(3.8)	142.5(12.1)b	120.7(10.8)b	35.13(4.09)	146.8(2.4)b
Average		62.8	106.0	92.8	34.37	
Statistical significance	P= 0.0089	P = 0.16	P = 0.13 $LSD_{0.05}$ = 59.90	P = 0.28 $LSD_{0.05}$ = 58.85	P = 0.42	P = 0.0219

Data between brackets correspond to standard error (SE) of the treatment mean value. Average values calculated when no differences were found.

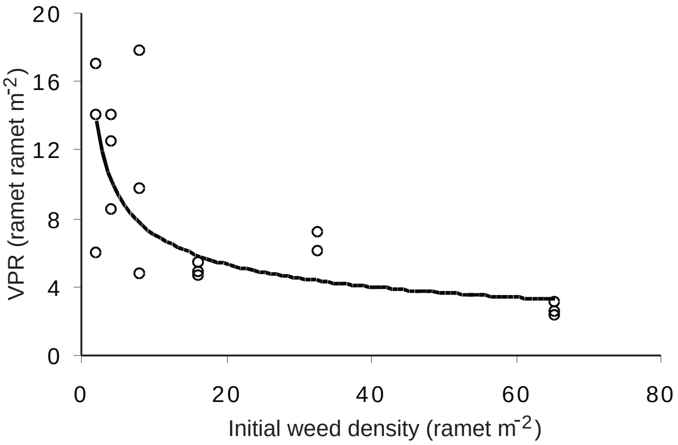

Fig. 1. Vegetative propagation rate (VPR) of *A. repens* in a partial additive competition experiment with onion cv "Valcatorce INTA". VPR = final ramet number per initial ramet.

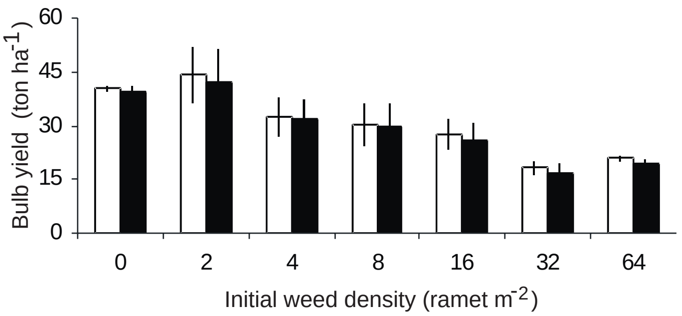

Fig. 2. Bulb yield in "Valcatorce INTA" onion under Russian knapweed competition for a range of 0-64 ramet m^{-2} of weed density at transplant. Bars indicate total (white) and commercial (black) yield (ton FW ha^{-1}). While statistical analysis was performed independently for each data series, differences presented (SNK, P<0.05) are valid for both.

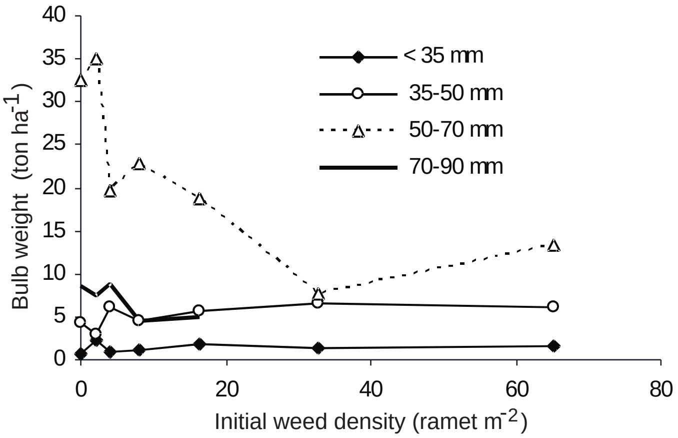

Fig. 3. Onion bulb yield for the most common commercial categories (discard, < 35 mm; size 2, 35-50 mm; size 3, 50-70 mm; size 4, 70-90 mm of eq. diameter) under competition with increasing densities of the invasive weed *A. repens*.

by averaging AR_0 and AR_2, observing 42.3 and 41.1 ton ha^{-1} for total and commercial bulb yield, respectively. In AR_{32} and AR_{64} the bulb production was statistically low in comparison with AR_0 and AR_2. An average of 19.6 ton ha^{-1} of total bulb yield (-54%) and 18.1 ton ha^{-1} of commercial bulb yield (-56%) were calculated. Intermediate treatments were intermediate in response as were cited for the other variables studied.

No bulb losses (discard) were observed at harvest due to phytopathological disorders. Low size (bulb equatorial diameter lower than 35 mm) was the unique cause for bulb discarding. There were no differences among treatments for this variable.

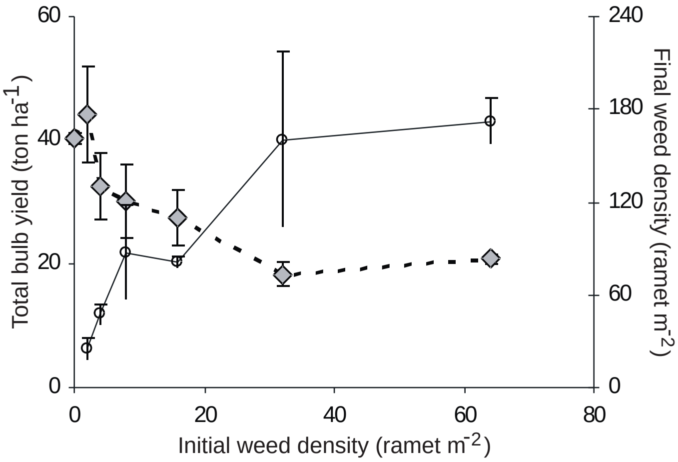

Fig. 4. Onion bulb yield (dot line) and final density of *A. repens* (full line) in a partial additive competition experiment with an initial weed density range of 0-64 ramet m^{-2}.

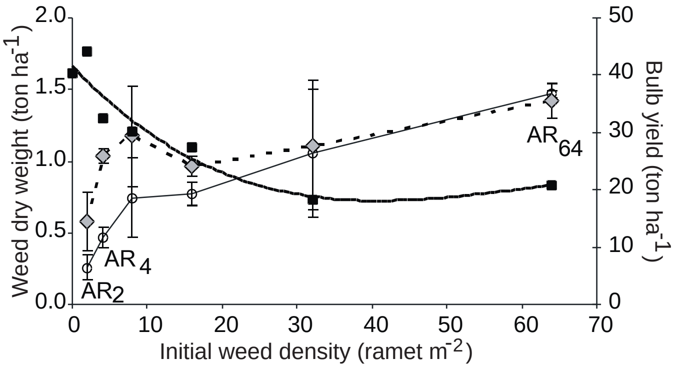

Fig. 5. Total Onion bulb yield (full line-thick) and final *A. repens* aboveground (dot line) and belowground biomass (full line-thin) for increasing *A. repens* initial density among 0-64 ramet m^{-2} in a partial additive competition experiment.

Mean bulb loss was 13.7 ± 3.28 % of the total bulb number and 5 ± 1.19 % in weight, equivalent to 1.2 ton ha^{-1} (Table 2).

As observed yield differences can not be explained by differential bulb loss among treatments. Plant mortality was 5.7 ± 1.4 % in average without differences among treatments (Table 2).

The average size for commercial bulbs decreased as initial weed density increased. The pattern of statistical differences was the same as observed for total and commercial yield. While the mean bulb diameter was 5.6 ± 0.1 cm for AR_0, the value for AR_{32} and AR_{64} was 20 % low (Table 2). The same grouping was observed

Table 2. Onion yield parameters under *A. repens* competition (0-64 ramet m^{-2} at transplant time)

A. repens initial density (ramet m^{-2})	Discard bulbs rate (number based) %	Discard bulbs rate (weight based) %	Onion plant mortality rate %	Commercial bulbs diameter (cm)
0	6.7(4.4)	1.6(1.1)	1.7(1.7)	5.6(0.1)a
2	4.9(2.9)	5.1(4.6)	0.0(0)	5.5(0.3)a
4	12.2(6.5)	3.0(1.7)	6.7(3.3)	5.3(0.2)a
8	6.7(6.7)	2.3(2.3)	5.0(0)	5.1(0.2)ab
16	18.3(11.7)	7.0(3.6)	8.3(8.3)	5.0(0.2)ab
32	24.1(13.0)	8.5(4.3)	10.0(0)	4.6(0.1)b
64	23.0(11.7)	7.5(3.9)	8.3(4.4)	4.7(0.1)b
Average	13.7	5.00	5.71	
P value	0.34	0.47	0.35	0.0344 *

Data between brackets correspond to standard error (SE) of the treatment mean value. Average values calculated when no differences were found.

for mean bulb fresh weigh (FW) at harvest. In AR_{32} and AR_{64} the calculated value was 52.97 ± 3.31 g FW $bulb^{-1}$, 47.3 % lower than AR_0 (100.60 ± 4.11 g FW $bulb^{-1}$). Intermediate treatments were also intermediate in response (Table 2). Fig. 3 demonstrates the incidence of weed density on bulb size for the most common categories. While size 3 bulbs (50-70 mm eq. diam.) were less represented at weed densities higher than 16 ramets m^{-2}, size 4 ones (70-90 mm eq. diam) were not present. Low size categories remained constant in proportion for the entire weed density experimental range.

Discussion

Onion is a poor competitor against weeds. Soares *et al.* (2003) reported a 95 % yield loss and 91 % of decrease in mean bulb weight for a 98 days period of weed competition. The complexity increases when perennial weeds are dominant. Creeping perennials normally have a higher relative growth rate than onion, with biomass accumulation, both above and belowground, sufficiently high to strongly compete with the crop.

For instance, onion yield losses due to volunteer potato (*Solanum tuberosum*) interference occur at densities commonly observed in the field. One plant per 14.9 m^{-2} resulted in 10% crop yield loss while 100% yield loss was achieved with 4 volunteer potato plants m^{-2}. Volunteer potato competition limits onion bulb size, resulting in a lower quality, less valuable crop (Williams *et al.,* 2004).

Because Russian knapweed is not controlled by herbicides in a crop context, yield losses due to weed interference could be severe. For 64 ramets m^{-2} Watson (1980) reported 75 % grain yield loss in wheat and 88 % in corn. Other weed control operations, like mechanical or hand weeding, are also ineffective because the weed regrow and extend from creeping roots. In this experiment we observed a 56 % average reduction in the onion commercial yield for 32-64 ramets m^{-2} at transplant.

While an increasing tendency was observed as weed density increased, non commercial bulb proportion was statistically constant for the complete range of Russian knapweed initial density. The observations reported a high coefficient of variation (CV = 1.10) as consequence of which no significant differences were detected among treatments. This variability was higher than that observed for total bulb yield (CV = 0.37) and also for commercial bulb yield (CV = 0.40).

Most reports indicate that certain plant traits are responsible for invasive weed dominance. As cited by Mashhadi and Radosevich (2004) and Rejmánek *et al* (2005) the list include i) vegetative propagation, ii) a high competitive ability in resource foraging, iii) high propagule pressure, iv) high seedling relative growth rate and specific leaf area, v) seed dispersal by vertebrates, vi) high phenotypic plasticity, and vii) allelopathy.

We suppose that Russian knapweed probably evidence various of these traits. In this experiment we observed at least three of these:

a) Vegetative propagation: Weed density increased along the experimental period as a consequence of vegetative propagation and interference relationships between species resulted which is a normal behaviour of creeping herbs. If we extrapolate the experimental VPR, it is possible to infer that low density patches would reach a density enough to strongly compete with onions in a second year. A similar behaviour would be expected under field conditions, at least in newly infected sites where belowground biomass tends to increase as a function of time.

From the statistical analysis applied to final ramet density no differences were found between the two lowest densities, AR_2 and AR_4, whose average value was 36.4 ramet m^{-2}. Additionally, no differences were observed between the two highest densities, AR_{32} and AR_{64}, for which the mean value was 168.4 ramet m^{-2} at harvest. Both groups were, in effect, different from each other. As in all variables under study, intermediate treatments had an intermediate response.

Total onion yield correlated well with both ramet density (Fig. 4, r =-0,75) and weed belowground biomass (Fig. 5, r =-0,68). The last two variables were clearly interdependent because, at least under our experimental conditions, ramet production was directly associated with root growth (r = 0.87).

The relation among belowground biomass-bulb yield and ramet density-bulb yield could not be observed for aboveground biomass, which in turn had a similar value for the entire range of weed density. This could be possible as a consequence of intra-specific canopy limitation in the Russian knapweed population.

b) Competitive ability: The best predictors for competition coefficients for pairs of species are: i) maximum plant size, ii) root biomass allocation, iii) time of emergence and iv) seed size (Freckleton and Watkinson, 2001). Russian knapweed is clearly a dominant competitor in relation to onion plants when the first three attributes from the list are considered.

It is generally assumed that root foraging traits are size symmetric in coexistent species. This implies that the intensity of resource acquisition is proportional to the size of the root system (Schwinning and Weiner, 1998). In this context, we can argue that the intensity of Russian knapweed plant competition would be a consequence of a higher size than onion plants.

However, Rajaniemi and Reynolds (2004) working with several herbs including *Centaurea maculosa*, which is similar to Russian knapweed, demonstrate size asymmetry in weed root foraging due to an anticipated use of limited soil nutrients. We also support this hypothesis with respect to Russian knapweed competition. In established patches of this weed there is a clonal root system that is both extensive and pre-existent as compared with any direct seeded or transplanted vegetable crop. Except for water, that is not limited under furrow irrigation, nitrogen (N) fertilization for instance is, both spatially and temporally concentrated. Conventional N applications are normally localized near the crop rows in two times along the crop cycle. Then, asymmetric competition resulted as consequence of the extension of the weed root system and also by an anticipated access to soil nutrients with respect to crop plants.

c) Propagule pressure: The persistence of an important bank of vegetative propagule allows us to understand the importance of controlling the progress of Russian knapweed invasion in agricultural fields at the LVRN. We must bear in mind the high cost of land and also the loss of agricultural aptitude in invaded soils. As cited by Soukup *et al.* (2004), crop losses and land degradation are common in both natural and agricultural systems affected by invasive weeds.

In the irrigated LVRN we have demonstrated the competitive ability of Russian knapweed over one of the most important vegetable alternatives in the south of Argentina and 2nd national vegetable crop with 25,000 ha cultivated area and 700,000 ton annual production (FAO, 2006).

Characterization of the vegetative propagation ability of Russian knapweed explained the constantly modified crop-weed interference relationship. It is important to gain knowledge about the importance of plant invasions and their impact in order to persuade the public and private sectors about the urgent need to limit the invasive weed dispersal and, additionally implement concrete plans for controlling established populations in both private agricultural and public sites.

Acknowledgements

This research was funded by the Universidad Nacional del Comahue throughout its Secretaría de Investigación and it is part of Carlos Bezic Doctoral thesis at Universidad Nacional del Sur, Bahía Blanca, Argentina. We specially thank undergraduate student Sergio Vazquez for field and lab support.

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