Growth interference of invasive Russian knapweed on “valcatorce INTA” onion

Carlos R. Bezic, Armando A. Dall Armellina, Omar A. Gajardo, Lucrecia M. Avilés and Silvia L. Cañón

Weed Ecology and Control Research Group, CURZA-University of Comahue (8500) Viedma, Río Negro province, Argentina. E-mail: malezas@uncoma.edu.ar

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 (40° 03' S; 62° 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 ≥ 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 Río Negro (LVRN), in particular, is located at the southeast of the Rio Negro province, near the Negro river outlet, at 40° 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 m²-100 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 m² greenhouse, located at the Universidad Nacional del Comahue (CURZA) campus in Viedma, Río Negro province, Argentina (40° 03' S; 62° 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 m² (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 cm³ plastic pots (64 cm²) 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): AR0 (crop check without weeds); AR2 (2 ramet m⁻²); AR4 (4 ramet m⁻²); AR8 (8 ramet m⁻²); AR16 (16 ramet m⁻²); AR32 (32 ramet m⁻²); AR64 (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 \( \text{p'} = \arcsin(\sqrt{p}) \), 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 AR2 and AR4 were lower in final weed density in comparison with AR32 and AR64. 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 AR2 and the lowest as 2.6 for AR64.

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 AR2 and AR32. AR64. Same results were obtained for the aboveground biomass in elongated plants (rosettes excluded) as shown in Table 1, were AR2 plots evidence a biomass lower than AR32 and AR64, 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 AR2 and AR4 with respect to AR4. 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 AR2 (\( p > 0.05 \)). In this case the reference values were calculated

<table>
<thead>
<tr>
<th>Initial density (ramet m⁻²)</th>
<th>Final density (ramet m⁻²)</th>
<th>Rate of elongated plants (%)</th>
<th>Total aboveground biomass (g DW m⁻²)</th>
<th>Aboveground biomass of elongated plants (g DW m⁻²)</th>
<th>Elongated plants height (cm plant⁻¹)</th>
<th>Belowground biomass (g DW m⁻²)</th>
</tr>
</thead>
<tbody>
<tr>
<td>2</td>
<td>25.2(6.7)a</td>
<td>76.7(6.2)</td>
<td>57.9(20.1)a</td>
<td>53.6(19.5)a</td>
<td>31.28(1.80)</td>
<td>25.8(8.8)ab</td>
</tr>
<tr>
<td>4</td>
<td>47.6(6.7)a</td>
<td>60.5(5.9)</td>
<td>103.4(5.0)ab</td>
<td>101.3(11.6)ab</td>
<td>32.62(1.36)</td>
<td>47.1(7.1)a</td>
</tr>
<tr>
<td>8</td>
<td>87.8(30.9)ab</td>
<td>64.8(6.9)</td>
<td>117.5(34.9)ab</td>
<td>96.4(29.1)ab</td>
<td>36.57(1.48)</td>
<td>74.6(28.0)ab</td>
</tr>
<tr>
<td>16</td>
<td>81.0(3.6)ab</td>
<td>55.2(3.3)</td>
<td>96.6(7.3)ab</td>
<td>82.0(5.3)ab</td>
<td>38.00(3.39)</td>
<td>77.3(8.4)ab</td>
</tr>
<tr>
<td>32</td>
<td>164.6(52.8)ab</td>
<td>61.6(4.7)</td>
<td>118.1(27.2)ab</td>
<td>102.7(25.4)ab</td>
<td>32.60(2.12)</td>
<td>105.6(44.4)ab</td>
</tr>
<tr>
<td>64</td>
<td>172.1(14.9)ab</td>
<td>58.2(3.8)</td>
<td>142.5(12.1)ab</td>
<td>120.7(10.8)ab</td>
<td>35.13(4.09)</td>
<td>146.8(2.4)ab</td>
</tr>
<tr>
<td>Average</td>
<td>62.8</td>
<td>106.0</td>
<td>92.8</td>
<td>58.85</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Data between brackets correspond to standard error (SE) of the treatment mean value. Average values calculated when no differences were found.
by averaging AR0 and AR2, observing 42.3 and 41.1 ton ha⁻¹ for total and commercial bulb yield, respectively. In AR32 and AR64 the bulb production was statistically low in comparison with AR0 and AR2. 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.

<table>
<thead>
<tr>
<th>A. repens initial density (ramet m⁻²)</th>
<th>Discard bulbs (number based) %</th>
<th>Discard bulbs (weight based) %</th>
<th>Onion plant mortality rate %</th>
<th>Commercial bulbs diameter (cm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>6.7(4.4)</td>
<td>1.6(1.1)</td>
<td>1.7(1.7)</td>
<td>5.6(0.1)</td>
</tr>
<tr>
<td>2</td>
<td>4.9(2.9)</td>
<td>5.1(4.6)</td>
<td>0.0(0)</td>
<td>5.5(0.3)</td>
</tr>
<tr>
<td>4</td>
<td>12.2(6.5)</td>
<td>3.0(1.7)</td>
<td>6.7(3.3)</td>
<td>5.3(0.2)</td>
</tr>
<tr>
<td>8</td>
<td>6.7(6.7)</td>
<td>2.3(2.3)</td>
<td>5.0(0)</td>
<td>5.1(0.2)</td>
</tr>
<tr>
<td>16</td>
<td>18.3(11.7)</td>
<td>7.0(3.6)</td>
<td>8.3(8.3)</td>
<td>5.0(0.2)</td>
</tr>
<tr>
<td>32</td>
<td>24.1(13.0)</td>
<td>8.5(4.3)</td>
<td>10.0(0)</td>
<td>4.6(0.1)</td>
</tr>
<tr>
<td>64</td>
<td>23.0(11.7)</td>
<td>7.5(3.9)</td>
<td>8.3(4.4)</td>
<td>4.7(0.1)</td>
</tr>
<tr>
<td>Average</td>
<td>13.7</td>
<td>5.00</td>
<td>5.71</td>
<td>5.0 ± 0.2</td>
</tr>
</tbody>
</table>

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_{4} (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 propague 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.

References


