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The effect of weeding time on raspberry (*Rubus idaeus* L.) crops yield and weed community in Rio Negro Province, Argentina

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ABSTRACT

Raspberry (*Rubus idaeus* L.) is the most important crop in the (Andean Shire), an area situated at the south of Rio Negro Province in the south of Argentina. Organic berries production in this area increased significantly in the last ten years. Weed management in raspberry organic crops is performed by tillage. Excessive tillage can reduce weed species diversity and increase both soil erosion and production costs. Field experiments were carried out with summer and fall fruiting raspberry varieties within the periods 2005–06 and 2006–07 with the aim of studying the effect of different weeding times on (i) raspberry yield, (ii) fruit quality and (iii) weed community richness and abundance. The fruit harvest was carried out two or three times a week during all harvest period for each variety. In addition, fruit quality was assessed at different harvest times. From spring to the end of harvest weed cover and weed species richness were measured for each treatment. The results showed that the most frequent weed removal did not exceed the yield obtained with three weeding operations carried out during spring and summer. This meant an important reduction in cost production, with the advantage of maintaining weed diversity. The presence of weeds did not affect fruit quality. Summer fruiting variety was more competitive than fall fruiting variety.

1. Introduction

Raspberry (*Rubus idaeus* L.) is the most important crop in the area called Comarca Andina (Andean Shire) situated at the south of Rio Negro Province in Argentina between 42° and 42° 20 ′S. The western border is formed by the Andes mountain range and the eastern by the meridian 71° W. This is the main production area of berries in Argentina. The most frequent crops are raspberry, strawberry (*Fragaria vesca* L.), cherry (*Prunus virginiana* L.), gooseberry (*Ribes* sp.), blackberry (*Rubus* sp. L.), blueberry (*Vaccinium* sp.) and boysenberry (*Rubus loganobaccus* L.) (Martínez et al., 2009). Two kinds of raspberry varieties are planted in the area. On one hand, varieties called summer or floricane fruiting with a harvest period along the summer whose floricanes die after fruiting. On the other hand, raspberry varieties called fall fruit or primocane fruiting have many advantages over traditional summer-fruiting, floricane raspberries. They provide an opportunity to extend the production season from late summer until fall. Whereas the summer raspberry harvest lasts 6 weeks, fall fruiting can add, at least, 6 weeks to the production season (Pritts, 2008). The main raspberry varieties planted in the Comarca Andina are Schoenemann and Autumn Bliss for summer and fall fruiting, respectively (Martínez et al., 2009).

Organic production systems have been significantly expanded in the Comarca Andina. The knowledge of population dynamics of different pests such as weeds, insects or pathogens is essential to design a successful strategy for pest management in production systems with or without reduced use of chemicals. Thus, it is possible to attain a sustainable production maintaining weed population size, which does not reduce significantly crop yield and does not alter the specific role of weeds as ecological services providers in agroecosystems (Radosevich et al., 1997). Competition is a key process regulating the effect of weeds on crop yield. Moreover, there is enough published information regarding the effects of environmental factors or agronomic practices on competition between weeds and crops. Although there are many studies in Argentina concerning weeds effects on extensive crops such as soybean, wheat, corn or sunflower, very few of them focus

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on studying the effect of weeds on intensive crops such as raspberry (Ovalle et al., 2007). In addition, there are no studies comparing the effect of different tillage strategies on crop yield and weed community structure. Interestingly, grass and clover cover crops, rototilling, hand weeding, sawdust mulch, and pre-emergence herbicides were evaluated for their effects on yield, berry weight, and total soluble solids in summer-bearing red raspberries. With the exception of total soluble solids, none of the evaluation criteria were significantly affected by the weed control treatments (Barney and Finnerty, 1994).

Mulching is a common weed management tool and can be very effective in reducing or eliminating most annual weeds from the crop row. However, it is seldom effective for perennial weeds (Bonnano, 2011 www.newenglandvfc.org/pdf_proceedings/Blueberry weed_manage.pdf). In the area of the study it is not usual to use this option in large surfaces because it is not easy to obtain vegetables residues. Hoe-weeding is the main method used in the Comarca Andina in organic raspberry. In addition, many arable weed species support a high diversity of insect species. Thus, excessive soil tillage may cause reduction in abundance of host plants affecting associated insects and other taxa. Weeding in the Comarca Andina is mainly done regardless of the competitive effect of weeds. The average cost of each weeding is 350 kg of raspberry that represents almost 4% of the crop production. Moreover, the costs increase regarding the amount of weeds present in the field. Thus, proper tillage is important in order to keep raspberry labor costs down. During 2005–06 and 2006–07, field experiments were carried out with the aim of studying the effect of different weeding regimes on (i) raspberry yield, (ii) fruit quality (weight, pH and Brix grade) and (iii) weed community richness and abundance in raspberry crops with both floricane and primocane fruiting habit.

2. Materials and methods

2.1. Site and experimental design

During 2005/06 and 2006/07 growing seasons, three field experiments were conducted in organic raspberry crops. Experiments were carried out in two different farms near the city of Lago Puelo that have been under organic management systems from more than ten years where soil organic matter is 7% and pH: 6.5. Prevalent soils in the area are Andosols derived from ash volcanic with loamy texture A horizon. They are highly fertile soils with adequate nutrient supply (with the exception of phosphorus). The average bulk density of these soils is 0.5 g/cm^3, N content 4 g kg^{-1} and C 74 g kg^{-1}. The climate is temperate with 75% of the annual rainfall in autumn–winter (between April and September) and both spring and summer (October–March) are generally warm and dry. The mean temperature and annual precipitation are 9.9 °C and 921 mm, respectively (Urretavizcaya, 2010). Temperature and rainfall regimes of the experimental area are shown in Fig. 1.

The crop life in the area is approximately 20 years. Raspberry planting is in lines 3.3 m apart and 0.5 m between plants in each line, in continuous hedgerow with two pair of wires at 1.3 m–0.7 m from the soil. Fertilization is carried out with organic chemical fertilizer incorporated in spring. Drip irrigation is applied regarding 6 mm average demand per day in January. The most serious problems are root diseases which are managed choosing planting site or with soil systematization. The most frequent weeding method is hand hoeing covering 1 m wide along the plant line. The areas between the crop rows are usually maintained with a mowed cover of sod, weeds, or a combination of these. This cover is used primarily for erosion control, to maintain biodiversity and to improve the recollection of fruits by harvesters.

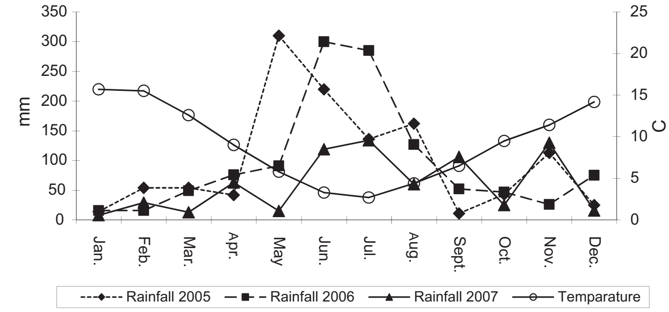

Fig. 1. Air average temperature and rainfall in the experimental area. Temperatures are average of (1997–2007). Rainfall data are from 2005, 2006, 2007.

The experimental design was a randomized complete block with five and four treatments in 2005–06 and 2006–07, respectively. In both years there were three replications for each treatment. The treatments consisted of different frequencies of weeding operations (hand hoeing) during spring (September–December) and summer (December–March) (Table 1). In 2005–06, the experiment was conducted only with the fall fruiting Autumn Bliss variety while in 2006–07, the experiments were carried out with Schoenemann (summer fruiting) and Autumn Bliss varieties. The experimental plots consisted of 5 m of crop line length. Each replication was placed in different lines of the crop. The time of weeding represents the calendar applied in the region and it is related to the weed cover (40–60%). The different hoeing operations were done in the first inches of soil to avoid damaging the roots and shoots of the crops along the plant line in a 1 m wide. The unweedy treatment was without tillage from the beginning of spring and agronomic practices such as irrigation, fertilization, insecticide and fungicide applications were the same in the different experiments as well as in the rest of the crop.

2.2. Data collection

2.2.1. Crop yield and fruit quality

To assess crop yield of Autumn bliss variety each plot was totally harvested by hand two or three times each week, from December (the beginning of summer) to April (mid-autumn). For Schoenemann variety the same harvest method was practiced from December to the end of January. In addition, individual fruit weight, pH and Brix grade (soluble solid contents) of the fruits were also measured. Samples of 50 fruits were taken each week and fresh weight was registered and fruits were preserved at −22 °C until they were analyzed. Brix grade is a measurement of refractometric soluble solids content (RSS) expressed in percentage and is equivalent to the concentration of total sugars in the fruit affecting the proportion of fruit and sugar used in the sweet industry.

2.2.2. Weed community and cover

From September of each year and every fifteen days until April, soil weed cover was visually estimated (0% unweedy − 100% total

Table 1
Different experimental treatments (times of weeding) in experiments (2005–06 and 2006–07). Numbers next to each month is the day of weeding.

2005–06 Autumn bliss	2006–07 Autumn bliss	2006–07 Schoenemann
Sep (11)–Nov (14)	Sep (10)–Feb (15)	Sep (10)–early Nov (10)
Oct (17)–Feb (26)	Sep–Nov (10)–Feb	Sep (10)–late Nov (22)
Sep–Nov–Feb	Weeded biweekly	Weeded biweekly
Weeded biweekly	Weedy	Weedy
Weedy		

weedy cover) by two trained persons in each experimental plot along the plant line in a 1 m wide with four quadrats of 0.25 m^2. In each sample, weed species were identified and the species richness (weed species number) and abundance of weed species in each plot was registered. Shannon diversity index (Magurran, 1988) was also registered. Shannon's index (1) accounts for both abundance and evenness of the species present. The proportion of species i relative to the total number of species (p_i) is calculated, and then multiplied by the natural logarithm of this proportion (lnp_i)

$$H = -\sum p_i \ln p_i \tag{1}$$

2.3. Statistical analysis

For each experiment, data was analyzed by ANOVA and when the P was <0.05, means were compared using LSD test ($P < 0.05$) corrected by Fisher. In order to homogenize variance Weed Cover (%) results were previously transformed in arc sin (x).

3. Results

3.1. 2005–06 Growing season

3.1.1. Crop yield and fruit quality

The total yield of fall fruiting raspberry varieties is generally achieved in two periods: 1) from the end of December to the end of January and 2) during February and March. Normally, the first harvest period represents more than 60% of the whole yield. In our study the average of the first forty days from the beginning of harvest (mid-December to end of January) represented 79% of the whole yield. No significant differences were observed between the yields of the various weeding treatments except when a single hoeing operation was conducted in October (Fig. 2). Raspberry yield in this treatment was not different compared to the weedy control, suggesting that only one weeding was not enough to reduce the effect of competition. Regarding the accumulated yield during the first harvest period, the yield rate increased between ten and twenty days from the beginning of harvest (Fig. 3). During the second period of harvest, from 4 Feb to 22 Apr, there were no significant differences in crop yield of treatments with different weeding regimes ($P > 0.05$). The total yield obtained in both harvest periods was not different ($P > 0.05$) between the biweekly weeding treatment and weeding carried out in Sep, Nov and Feb (0.74 ± 0.08 and 0.69 ± 0.07) kg/m^2, respectively.

Fruit quality was not affected by weeding regimes. In the average of the treatments these figures were 135.5 (±5.2), 8.86 (±0.38) and 3.23 (±0.04) for fruit weight, Brix grade and pH, respectively. Interestingly, the fruit weight and solid soluble content showed an increase before the end of the harvest. The opposite was observed for the pH (data not shown).

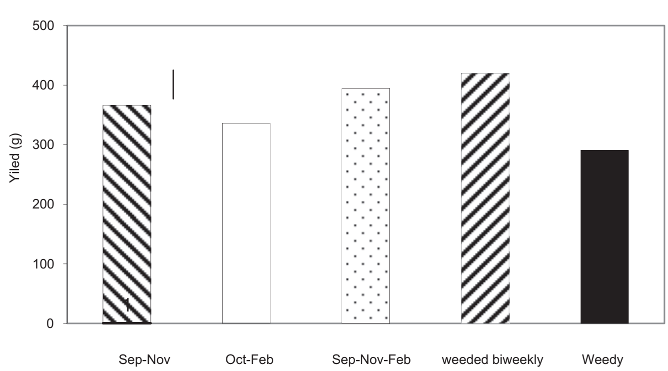

Fig. 2. Average yield (g/m^2) for the first harvest period (December–January) in each experimental treatment on 2005–06 experiment. The insert bar is the LSD ($P < 0.05$).

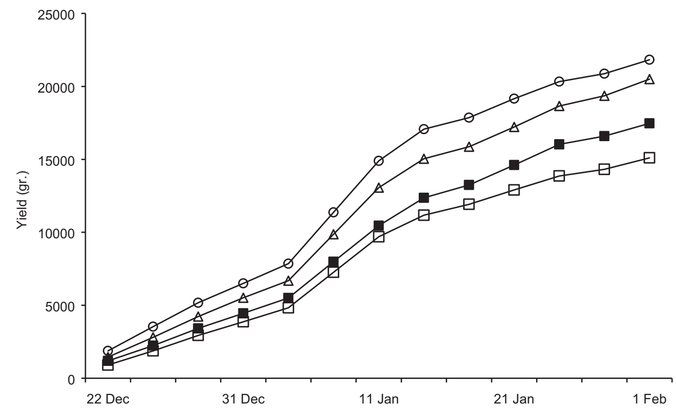

Fig. 3. Accumulated yield (g/5 m^2) during 40 days from the beginning of harvest in each experimental treatment on 2005–06 experiment. Oct (■), Sep–Nov (Δ), weeded biweekly (○), weedy control (□).

3.1.2. Weed community cover and composition

There was a significant ($P < 0.05$) effect of different treatments on weed cover. From mid-December to mid-February, the plots weeded in October had more weed cover than those weeded with tillage in September and November (Fig. 4). On the other hand weeding every fifteen days reduced significantly ($P < 0.05$) the species richness at the end of harvest (Table 2). The Shannon index was lower in the intensive weeding treatment than in the other treatments (data not shown). Most relevant grass weeds were *Agropyron repens* L. and *Poa pratensis* L. and *Ranunculus repens* L. and *Rumex obtusifolius* L. were the main broadleaved weeds.

3.2. 2006–07 Growing season

3.2.1. Crop yield and fruit quality

The effect of weeding times in crop yield of Autumn Bliss variety showed the same trend as in 2005–06. In both harvest periods there were no differences between the continuously weeded plots and the treatment with weeding carried out in September,

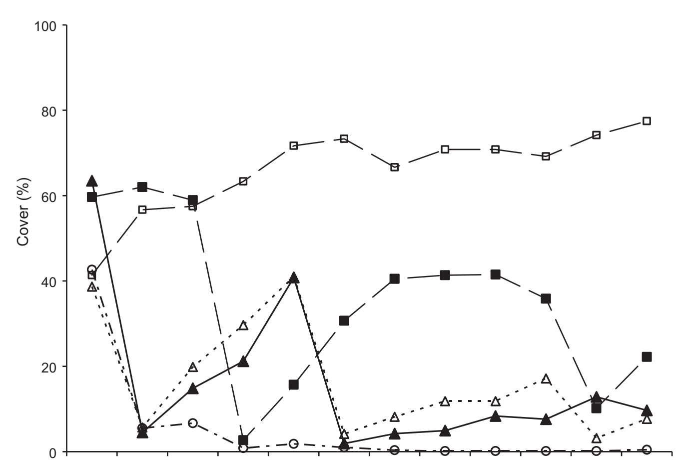

Fig. 4. Weed cover (%) in each experimental treatment from September to beginning of April on 2005–06. Sep–Nov (▲), Oct–Feb (■), Sep–Nov–Feb (Δ), weeded biweekly (○), weedy control (□).

Table 2
Species richness at the end of harvest in each experimental treatment on the experiment 2005–06. Data with different letter are significantly different ($P < 0.05$).

Experimental treatment	Species richness
September–November	3.7a
October–February	4.3a
September–November–February	5a
Weeded biweekly	1.7b
Weedy check	4.7a

Table 3
Average fruit quality (Weight, Brix grade and pH) for different harvests in 2006–07 experiment on Autumn bliss variety. Data with different letter are significantly different ($P < 0.05$).

Time of harvest	Fruit weight (g/50 fruit)	Brix grade	pH
First harvest	113.6a	10.5	3.16
Second harvest	71.7b	11	3.04

November and February (Fig. 5). The yields of the second harvest period were 16 g/m^2 in the weedy control, and 26 g/m^2 and 22 g/m^2 in the continuously weeded and the treatment with weeding carried out in September, November and February, respectively. Interestingly, Schoenemann variety showed no significant effect of different weeding treatments on fruit yield ($P > 0.05$). As in 2005/06, weeding treatment did not affect fruit quality. On the Autumn bliss variety, the average fruit weight, pH and Brix grade were 87.3 (±6.2) g/50 fruits, 10.8 (±0.34) and 3.07 (±0.18), respectively. Although there was no effect of different treatments, fruit weight was affected by the time of harvest (Table 3). On Schoenemann (data not shown), these figures were 117.1 (±12.2) g/50 fruits; 9.02 (±0.32) and 3.32 (±0.16) for fruit weight, pH and Brix grade, respectively.

3.2.2. Weed community cover and composition

There was a significant ($P < 0.05$) effect of the weeding treatments on weed cover both in Autumn bliss (Fig. 6) and Schoenemann (data not shown) experiments. Similarly to the previous year, the number of weed species was lower ($P < 0.05$) in the continuously weeded treatment and there were no differences between the other treatments. Species richness was 6.6 (±0.7); 5.6 (±0.65); 3.3 (±0.28) and 1.3 (±0.09) for the treatments with weeded in Sep; Sep–early Nov, Sep–late Nov and each fifteen days assessed at the end of harvest.

4. Discussion

The early yield (from December to February) of primocane fruiting varieties is the product of the canes from the previous growing season that began to grow in the last spring, while the second harvest (February–April) comes from the poles that sprouted and grew during the current season (Martinez and De Michelis, 2009). The early yield results obtained in this study suggest that at least two weeding operations are needed previous to the beginning of harvest to avoid yield losses from weed competition. The residual weed populations in this treatment do not represent a major yield hazard. On the contrary, this is advantageous because of the possibility of maintaining soil cover as a means to protect it from erosion (Ovalle et al., 2007) and in addition to reduce the costs for human labors which represent a significant component in the raspberry production system. The lower fruit yield on weedy plots shows that weeds present at the end of spring and beginning of summer caused significant yield losses.

Although differences between treatments were observed from the initial stages of harvest in all treatments, these differences were particularly significant during the first three weeks of January. Thus, there might be a critical period of fifteen to twenty days that determines yield during the first harvest. The same response was also registered in other years (Martinez, personal communication). Assuming that it takes approximately 40 days from blossom to ripened fruit, it is possible to estimate that the time of flowering which gave rise to a significantly higher yield, was early December. At this time, the raspberry crop was in full emergence and growth of new shoots that increase (i) intra individual competition between different sinks of the plant, (ii) intra specific competition among plants and (iii) inter specific competition (raspberry crop-weed species). In annual crops it has been shown experimentally that the potential yield performance is directly associated with environmental factors such as radiation and temperature around anthesis (Satorre and Slaffer, 1999). Thus, knowing crop phenology and the relationship between time of flowering and levels of those environmental factors that define potential yield, the latter could be estimated for different varieties (Magrín et al., 2005). Regarding the second harvest period, the results suggest a possible compensation mechanism in the partitioning of photoassimilates in plants with lower production during the first harvest. In addition, it should be taken into account that aggressiveness of weeds decreases during the final stages of their cycle, due to their lower growth rate (Salisbury and Cleon, 1994). It is also relevant to point out that fruit weight was significantly higher in the first harvest

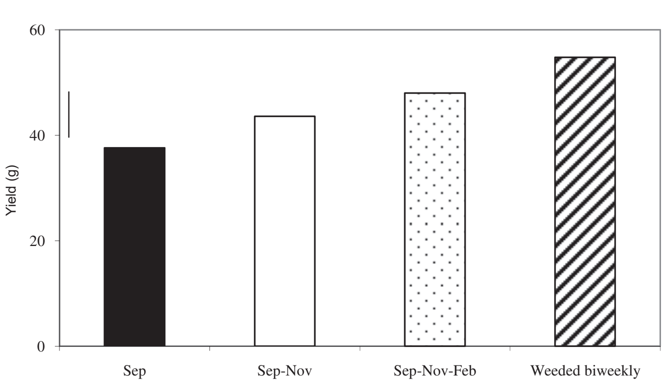

Fig. 5. Average yield (g/m^2) for all harvest period (December–April) in each experimental treatment on 2006–07 experiment (Autumn bliss variety). The insert bar is the LSD ($P < 0.05$).

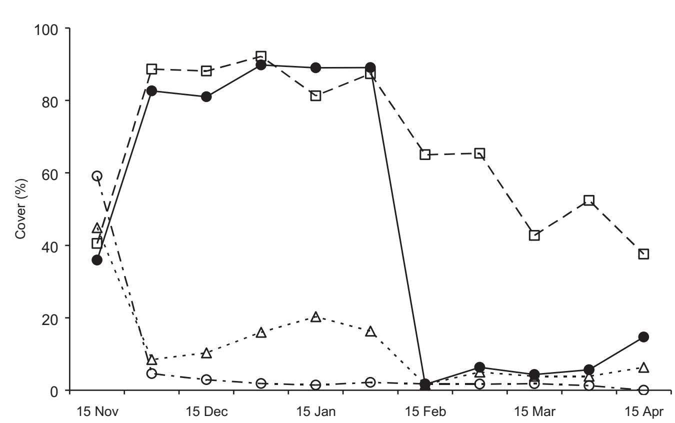

Fig. 6. Weed cover in each experimental treatment on 2006–07 experiment (Autumn bliss variety). Sep (□), weeded biweekly (○), Sep–Nov–Feb (Δ), Sep–Feb (●).

than in the second harvest period (Table 3). Thus, with hand weeding carried out in September–November and February it is possible to achieve not only a higher yield but also higher proportion of larger fruits.

Fruit weight was not affected by the different treatments. This suggests that the main yield component responsible for yield variation is the number of fruits per unit area. This result is similar to that registered on other crops (Magrín et al., 1993). Fruit quality was not affected by different weeding regimes. However, there were changes registered both in Brix grade and pH at the end of the harvest period. As the season progresses, the fruits increase their concentration of soluble solids (De Michelis, 2006). In these studies the highest values were registered previous to the end of harvest (end of March to mid-April). The decrease of this parameter in the last samples coincides with the first frosts and rainfalls.

Weed cover registered from early September to late January showed the effectiveness of different experimental treatments. Weeding every 15 days resulted in weed cover values always below 10%. In contrast, the weedy check always had values greater than 55% over the same period. Although there were differences in coverage between the continuously weeded treatment and the treatments weeded in Sep, Nov and Feb, this was not reflected in crop yield. These results suggest that there is a critical weed competition period from mid-November to mid-December. As expected, at the end of the harvest the number of weed species present was lower in the continuously weeded treatment that in the other treatments. Strategic weeding not only maintains crop yield but also results in higher diversity than more intensive weeding regimes. This plant diversity would help to increase the content of soil organic matter and biodiversity in general. The recent expansion of the organic farming area is expected to enhance the biodiversity of agricultural habitats (Albrecht and Mattheis, 1998). It can be hypothesized that organic cropping practices support a higher number of weed species than conventional cropping and also to favor herbicide-susceptible and less-nitrophilous species (Hyvonen et al., 2003). Number of species was used as a measure of diversity in many studies (Hald, 1999; Hyvonen and Salonen, 2002). However, other studies include also evenness to evaluate the weed community diversity (Scursoni et al., 2006). In the present study, the Shannon diversity index (Magurran, 1988) indicates lower diversity in most intensively weeded regimes. Certain weeds present in the experimental plots, such as *Poa annua* L. and *R. obtusifolius*, are important for biodiversity because of their significance for both invertebrates and birds (Marshall et al., 2003).

In conclusion, regarding the fall fruiting varieties and the whole yield, the most successful strategy is to weed the fields in September, November and February to get a large volume of fruit in the period between late December and throughout January. More intensive weeding regimes produce an effective permanent weed control, but without significantly increase in crop yield and reducing weed diversity community. In addition it has some drawbacks such as higher costs, excessive mineralization with loss of organic matter caused by soil movement, greater risk of damage to the plants (possible entry of pathogens) and also shoots breakage that reduce crop performance. These results show that, in order to obtain high yields, the complete elimination of weeds in crop line, which is frequently practiced by farmers in intensive weeding programs, is unnecessary.

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