Crop Protection 64 (2014) 51–59

Contents lists available at ScienceDirect

Crop Protection

journal homepage: www.elsevier.com/locate/cropro

Effects of mechanical and chemical methods on weed control, weed seed rain and crop yield in maize, sunflower and soyabean

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ARTICLE INFO

Article history:
Received 11 July 2013
Received in revised form
26 May 2014
Accepted 2 June 2014
Available online

Keywords:
Integrated weed management
Mechanical inter and intra-row weed control
Maize
Sunflower
Soyabean
Weed seed rain

ABSTRACT

Eight field experiments with maize (*Zea mays* L.), sunflower (*Helianthus annuus* L.) and soyabean (*Glycine max* (L.) Merr.) were carried out in central Italy in order to evaluate the effects of mechanical and chemical methods (spring-tine harrowing, hoeing, hoeing-ridging, split-hoeing, finger-weeding, herbicides in the row + inter-row hoeing, herbicides broadcast) on weed control, weed seed rain and crop yield. The choice of chemical and mechanical treatments in maize and soyabean compared to sunflower, required to be managed more carefully in order to maximize the weed control reducing yield losses. A global rating of weed control methods, based on their weed control efficacy, was obtained as useful means to assist farmers and technicians to choose the more appropriate weed control method. The combination of herbicides intra-row and hoeing inter-row gave best efficacy (on average 99% of weed control), with a 50% reduction in the chemical load in the environment. Hoeing-ridging gave good results, both inter- and intra-row (on average 93% of weed control); this method was also effective in reducing competitive ability and seed production of uncontrolled weeds. Split-hoeing or finger-weeding showed some limitations giving satisfactory results only when combined. Harrowing gave lowest weed control, although when combined to other mechanical methods, can help achieve a better efficacy.

1. Introduction

Over the last fifteen years, environmental and human health impact of herbicides use, increasing of herbicide resistance, the scarce availability of herbicides for minor crops such as vegetables and the increased of organic farming were the main factors that stimulated the interest to develop new methods for mechanical weed control to use alone or with herbicides in integrated weed control strategies (Melander et al., 2005; Cloutier et al., 2007). Recently, Harker and O'Donovan (2013) stressed as "given herbicide-resistant weed issue and consistent public pressure to reduce overall pesticide use, herbicide alternatives and true integrated weed management (IWM) strategies are urgently required now more than ever." Furthermore, the authors noticed as the importance of using alternatives to herbicides for weed control was recognized long ago (from 1929); although unfortunately, in modern agriculture, non chemical weed control methods have not always held a prominent place, and too often is common a "false integration" consisting of only chemical control components (i.e. different ways of applying herbicides, applying different herbicidal mode of action). Many others authors have challenged weed researchers to increase emphasis on IWM systems and alternatives to herbicides in order to develop systems that give producers more flexibility and options (Wyse, 1992; Buhler, 1999; Hamill et al., 2004). In this context, the priority to implement a true integrated weed management is mainly required in industrial crops where there is a large availability and application of herbicides. The most important industrial crops in Italy, excluding soft and durum wheat, are maize, soyabean and sunflower with 808,317 ha, 174,934 ha and 107,000 ha of arable areas, respectively (Istat, 2013).

In row crops, although weeds between the rows (inter-row weeds) can normally be controlled by ordinary inter-row cultivation, such as hoeing, weeds that grow within the line of row crop plants (intra-row weeds) have a great impact on yield and constitute a major problem for selective control, especially for organic farmers (Vangessel et al., 1995; Melander and Rasmussen, 2001; Ascard and Fogelberg, 2002; Pannacci et al., 2007a; Melander et al., 2012). For intra-row weed control, most mechanical methods are based on old principles, but new implements and improved versions have emerged lately, such as finger-weeder,

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http://dx.doi.org/10.1016/j.cropro.2014.06.001
0261-2194/

torsion-weeder and intelligent weeders (Van der Weide et al., 2008; Rasmussen et al., 2012).

Most of the European researches on mechanical weed control have been published through the workshops proceedings of the Physical and Cultural Weed Control Working Group, organized under the European Weed Research Society (http://www.ewrs.org/pwc). Some authors have summarized various suitable machinery adjustments for different crops and weed stages, in the form of technical guide for farmers in order to increase a correct use of mechanical weed control methods (Van der Schans et al., 2006).

In Italy, the mechanical methods used traditionally for weed control in maize, soyabean and sunflower are hoeing and hoeing-ridging. Over the last ten years new mechanical weed control methods such as split-hoeing, finger-weeding and harrowing were introduced in order to give farmers more flexibility and options (Frondoni and Bàrberi, 2000). However, there is a low availability of data on the performance of mechanical weed control methods obtained from field experiments in different years and in different crops. These data seems to be necessary and useful to assist farmers and technicians to select the more appropriate weed control method in order to adopt a rational Integrated Weed Management. For these reasons, the aim of this study was to evaluate the effects of mechanical and chemical methods on weed control, weed seed rain and crop yield in maize, sunflower and soyabean in central Italy. The mechanical treatments involved in this study were chosen with the aim to compare weed control methods traditionally used in Italy (i.e. hoeing and hoeing-ridging) with weed control methods relatively new such as split-hoeing, finger-weeding and harrowing. Several initial studies have supported this choice, showing that these mechanical methods may have application in maize, soybean and sunflower (Balsari et al., 2002; Raffaelli et al., 2002a, 2002b; Pannacci and Covarelli, 2003).

2. Materials and methods

From 2002 to 2005, eight field experiments with maize, sunflower and soyabean were carried out in central Italy (Tiber valley, Perugia, 42°57′N – 12°22′E, 165 m a.s.l.) on a clay-loam soil (24.8% sand, 30.4% clay and 0.9% organic matter). The trials were carried out according to good ordinary practices, as concerns soil tillage and seedbed preparation (Bonciarelli and Bonciarelli, 2001); in all cases, soft winter wheat was always the preceding crop. Experimental design was always a randomized block with three replicates and plot size of 45 m^2 (3 m width). In each crop, different weed control methods were compared (Table 1) and untreated plots were added as checks. Harrowing was applied before other mechanical treatments (hoeing, hoeing-ridging and split-hoeing + finger-weeding) with the aim to reduce initial competitiveness of weeds toward crops (Table 1). However, in 2004 and 2005 harrowing was also applied alone in order to know its weed control ability. Herbicides applied in broadcast applications and in band on the row integrated with hoeing in inter-row were added as chemical control and as integrating of chemical and mechanical control, respectively (Table 1). Herbicide were always applied with a knapsack plot sprayer fitted with four flat fan nozzles (Albuz APG 110 – Yellow) and calibrated to deliver 300 L ha^{-1} spray solution at 200 kPa pressure; applications were performed broadcast or in band on the row (50% of total surface).

Hoeing, an inter-row mechanical control, was carried out with a 3 m-wide powered rotary hoe (Model CERES, Badalini, Italy, http://www.badalini.it/home_en.php?azione=scheda_prodotto_en&id=50) at a cultivation depth of 50–60 mm, a driving speed of 4 km h^{-1} and leaving 120-mm untilled strip in the crop rows. Hoeing-ridging was carried out with the same rotary hoe as mentioned above, but equipped with ridging implements to bury weeds along the row. Harrowing, a full surface mechanical control, was carried out with a 3 m-wide spring-tine harrow (Type SF-30, Faza, Italy, http://www.fazasrl.com/index_inglese.htm, equipped with 7 mm-diameter flexible tines) at a cultivation depth of 10–20 mm and a driving speed of 7 km h^{-1}. Split-hoeing was performed with an Asperg Gartnereibedarf split-hoe (Asperg, Germany, for more details see Tei et al., 2002) at a cultivation depth of 30–40 mm, a driving speed of 3 km h^{-1} and leaving a 100-mm untilled strip in the crop rows. Split-hoe is an inter-row mechanical mean equipped with goosfoot tine cultivators in front and rotors with steel tine in rear moved by hydraulic power. The goosfoot tine cultivators penetrate and lift the earth, the rotors, turning in the direction of travel between the rows, intercept and crumble the soil and separate (split) earth and weeds. The weeds remain on the soil surface and die quickly. Metal crop shields (100 mm wide) protect crops from moving soil.

Finger-weeding, an intra-row mechanical control, was carried out with a Kress finger-weeder (Kress Umweltschonende Landtechnik, Germany, http://www.kress-landtechnik.de/wEnglisch/produkte/gemuesebau/hacktechnik/fingerhacke_start.shtml?navid=12) at a cultivation depth of 10–30 mm and a driving speed of 5 km h^{-1}. Kress finger-weeder equipments were mounted on Kress Argus System (Kress Umweltschonende Landtechnik, Germany, http://www.kress-landtechnik.de/wEnglisch/produkte/gemuesebau/hacktechnik/argus_start.shtml?navid=19) equipped with special-flat share type "Holland" (340 mm wide, http://www.kress-landtechnik.de/wEnglisch/produkte/gemuesebau/hacktechnik/hackwerkzeug/hackwerkzeuge_start.shtml?navid=31) that works between the rows. Rubber fingers grip from the

Table 1
Treatments in the field experiments with maize, sunflower and soyabean.

Treatments, relative times and codes*		Maize			Sunflower			Soyabean	
1st treatment	2nd treatment	2002	2003	2004	2002	2003	2004	2004	2005
Herbicides broadcast (HB)		X	X	X	X	X	X	X	X
Herbicides on row (HR) +	Hoeing (HO)	X	X	X	X	X	X	–	–
Harrowing (HA)		–	–	X	–	–	X	X	X
Harrowing (HA) +	Harrowing (HA)	–	–	–	–	–	–	X	X
Hoeing (HO)		–	–	–	X	X	X	–	–
Hoeing-ridging (HOR)		X	X	X	X	X	X	–	–
Harrowing (HA) +	Hoeing (HO)	–	–	–	–	–	X	X	X
Harrowing (HA) +	Hoeing-ridging (HOR)	X	X	X	–	–	–	–	–
Split-hoeing (SH)		X	X	X	X	X	X	X	X
Finger-weeding (FW)		X	X	X	X	X	X	X	X
Split-h. (SH) + Finger-w. (FW)		X	X	X	X	X	X	X	X
Harrowing (HA) +	Split-h. (SH) + Finger-w. (FW)	–	–	X	–	–	X	–	–

*Each treatment was applied only one time. First and second treatments were carried out in two different periods.