Agricultural Systems 121 (2013) 117–129

Contents lists available at ScienceDirect

Agricultural Systems

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

Operational planning of herbicide-based weed management

Mariela V. Lodovichi [a,*], Aníbal M. Blanco [b], Guillermo R. Chantre [a], J. Alberto Bandoni [b], Mario R. Sabbatini [a], Mario Vigna [c], Ricardo López [c], Ramón Gigón [c]

[a] Departamento de Agronomía/CERZOS, Universidad Nacional del Sur/CONICET, Bahía Blanca 8000, Buenos Aires, Argentina
[b] Planta Piloto de Ingeniería Química, Universidad Nacional del Sur/CONICET, Bahía Blanca 8000, Buenos Aires, Argentina
[c] EEA INTA Bordenave, Bordenave 8187, Buenos Aires, Argentina

ARTICLE INFO

Article history:
Received 20 December 2012
Received in revised form 24 May 2013
Accepted 26 July 2013
Available online 19 August 2013

Keywords:
Weed management
Planning model
Herbicide applications
Environmental impact
Winter wheat
Wild oat

ABSTRACT

Weeds cause crop yield loss due to competition, interfere with agricultural activities and reduce grain quality due to seed contamination. Among the numerous methods for weed control, the use of herbicides is the most common practice. Nowadays, the optimization of herbicide application is pursued to reduce the environmental impact, delay the appearance of herbicide-resistant weed populations, and improve the cost/benefit ratio of the agronomic business. This work proposes an operational planning model, aimed at calculating the optimal application times of herbicides in no-tillage systems within a growing season in order to maximize the economic benefit of the activity while rationalizing the intensity of the applications with respect to expert-knowledge-based recommendations. The model can decide on herbicide applications on a daily basis, consistent with timing of agricultural activities, and provides an explicit quantification of the environmental impact as an external cost. The proposed approach was tested on a winter wheat (*Triticum aestivum*)–wild oat (*Avena fatua*) system, typical of the semiarid region of Argentina. In all the studied scenarios at least two pre-sowing applications of non-selective herbicides were required to effectively control early emerging weed seedlings. Additional pre-sowing and post-emergence applications were also advised in cases when competitive pressure was significant.

1. Introduction

Weed control in crops is mainly based on the use of herbicides because they are efficient and easily applied. However, nowadays, attempts are made to minimize the use of chemicals in order to mitigate environmental impact and to avoid the appearance of herbicide-resistant weed populations (Pannell et al., 2004; Parsons et al., 2009). The optimization of weed control is largely recognized to be a challenging and information demanding task. Wiles et al. (1996) consider that a decision maker needs information about weed emergence patterns, crops competitive ability, impact of weeds on crop yield and quality, and on available management options.

In order to integrate the available information and systematically explore weed control options, several model-based decision support systems (DSS) have been developed in recent years (Table 1).

Since weeds are adapted to specific agro-ecological conditions, the DSS are not supposed to be used beyond their design scope without proper adjustments. Therefore, in all cases the studied weed/crop system is reported together with the country (or region within a country) of origin (Table 1). Moreover, major modeling components, classified as climatic, biological and economic, are also identified. The climatic component makes reference to an explicit use of weather data, while the biological component reflects the quantitative modeling of some of the most important eco-physiological sub-processes (emergence, seedling survival, seed production, etc.). This component is further classified as empirical or mechanistic, recognizing that the mechanistic approach makes use, in general, of some amount of empirical information.

Most DSS are devoted to typical annual weeds in wheat based rotations (Cousens et al., 1986; Doyle et al., 1986; Berti et al., 2003; Pannell et al., 2004; Parsons et al., 2009), but other crops, such as soybean and sugar beet, have also been modeled (Berti and Zanin, 1997; De Buck et al., 1999; Rydahl, 2004). Most systems were also designed in European countries (Cousens et al., 1986; González-Andújar and Fernández-Quintanilla, 1991, 2004; Berti and Zanin, 1997; Falconer and Hodge, 2001; Berti et al., 2003; Colbach et al., 2007; Parsons et al., 2009; Torra et al., 2010). However, it is evident that the automation of weed control management is of worldwide interest since there are also examples from Australia (Pannell et al., 2004), Africa (Mullen et al., 2003) and America

* Corresponding author. Address: Departamento de Agronomía, Universidad Nacional del Sur, Av. Colón 80, Bahía Blanca 8000, Argentina. Tel.: +54 291 4595102; fax: +54 291 4595127.

E-mail addresses: mlodovichi@criba.edu.ar (M.V. Lodovichi), ablanco@plapiqui.edu.ar (A.M. Blanco), gchantre@criba.edu.ar (G.R. Chantre), abandoni@plapiqui.edu.ar (J.A. Bandoni), cesabbat@criba.edu.ar (M.R. Sabbatini), mvigna@bordenave.inta.gov.ar (M. Vigna), rllopez@bordenave.inta.gov.ar (R. López), ramongigon@yahoo.com.ar (R. Gigón).

0308-521X/$ - see front matter © 2013 Elsevier Ltd. All rights reserved.
http://dx.doi.org/10.1016/j.agsy.2013.07.006

Table 1
Model based weed management DSSs.

Reference/ denomination	Weed/crop	Country of development	Model components			Evaluation approach			Scope		Environmental impact[d]
			Climatic[a]	Biological[b]		Economic	Simulation	Optimization[c]	Operational	Tactical/ strategic	
				Empirical	Mechanistic						
Doyle et al. (1986) and Cousens et al. (1986)	*Alopecurus myosuroides*, *Avena fatua*/ winter wheat	United Kingdom		X		X	X			X	
Sells (1995)	*Avena fatua*, *Alopecurus myosuroides*	United Kingdom		X		X		X		X	
Wiles et al. (1996)/GWM	General	USA		X		X	X			X	
Berti and Zanin (1997), Berti et al. (2003)/ GESTINF	16 weed species/ soybean, wheat	Italy		X		X	X				X
De Buck et al. (1999)/ BESTWINS	4 weed species/sugar beet	The Netherlands		X		X		X	X	X	
Falconer and Hodge (2001)	General	United Kingdom		X		X		X		X	X
Mullen et al. (2003)	*Striga* sp.	Mali		X		X		X			
González-Andújar and Fernández-Quintanilla (1991, 2004)	*Avena sterilis*, *Lolium rigidum*	Spain		X			X			X	
Pannell et al. (2004)/RIM	*Lolium rigidum*	Australia		X		X	X			X	
Rydahl (2004)/ CPO	75 weed species/11 crops	Denmark		X				X		X	
Colbach et al. (2007)/ ALOMYSYS	*Alopecurus myosuroides*	France	X		X		X		X	X	
Parsons et al. (2009)/Weed Manager	13 weed species/ winter wheat	United Kingdom	X		X	X		X	X	X	
Torra et al. (2010)/PIM	*Papaver rhoeas*	Spain		X		X	X			X	
This paper	*Avena fatua*/ winter wheat	Argentina		X		X		X	X		X

[a] Considered in a quantitative fashion (degree days, etc.).
[b] Considers items such as: seed survival, dormancy, germination, pre-emergence growth, seedling survival, tillering, heading, flowering, and seed production.
[c] Implements a numerical optimization algorithm to perform the search.
[d] Considered in a quantitative fashion.

(Wiles et al., 1996). Regarding the type of biological model, most systems are based on dynamic population balances (i.e., seeds present in the seedbank, emerged seedlings, number of mature plants) whose flows are described through empirical parameters (González-Andújar and Fernández-Quintanilla, 1991, 2004; Pannell et al., 2004). In the cases where the biology is more mechanistically represented (Colbach et al., 2007; Parsons et al., 2009) weather data is also required.

Economic analyses are also performed in most DSS in order to evaluate the potential profit of implementing different control procedures (Cousens et al., 1986; Wiles et al., 1996; Berti and Zanin, 1997; Falconer and Hodge, 2001; Berti et al., 2003; Pannell et al., 2004; Parsons et al., 2009; Torra et al., 2010). Regarding the evaluation approach, most systems are designed to be used in a simulation-oriented fashion, meaning that a certain strategy is proposed and its effect on the weed–crop system is calculated (González-Andújar and Fernández-Quintanilla, 2004; Pannell et al., 2004). In this way, different possible scenarios can be tested and ranked according to their economic output. However, due to the combinatorial amount of feasible control options (chemical and non-chemical) on a long term time-horizon of several seasons, some DSS also implement numerical optimization algorithms to automate the search (Sells, 1995; De Buck et al., 1999; Falconer and Hodge, 2001; Mullen et al., 2003; Rydahl, 2004; Parsons et al., 2009).

Regarding the scope of application, the conducted research on DSS development has been basically focused on the tactical/strategic planning problem, which addresses the weed control decisions over a long-term horizon of several years. In this regard, the DSS divide the seasons into periods of biological and agronomic sense, rather than using a daily step, to perform the calculations and implement the control operations. Finally, although all the DSS are designed to rationalize the chemical use and mitigate the environmental impact of weed control, only two models explicitly perform some quantitative evaluation of an environmental impact related indicator. Specifically, in Berti and Zanin (1997) and Berti et al. (2003) the potential contamination of groundwater is considered, while in Falconer and Hodge (2001) the impact of pesticides application is analyzed within a bi-objective (economic-environmental) optimization approach.

From the above review, it can be stated that the contributions are basically focused on the tactical/strategic planning problem. To the best of our knowledge, no proposals related to the herbicide