Agriculture, Ecosystems and Environment 251 (2018) 203–217

Contents lists available at ScienceDirect

Agriculture, Ecosystems and Environment

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

Research Paper

Landsharing vs landsparing: How to reconcile crop production and biodiversity? A simulation study focusing on weed impacts

Nathalie Colbach[a,*], Stéphane Cordeau[a], Alexia Garrido[a], Sylvie Granger[a], Daniel Laughlin[b,c], Benoît Ricci[a], Fiona Thomson[d], Antoine Messéan[e]

[a] Agroécologie, AgroSup Dijon, INRA, Univ. Bourgogne Franche-Comté, F-21000 Dijon, France
[b] Environmental Research Institute and School of Science, University of Waikato, Private Bag 3105, Hamilton 3240, New Zealand
[c] Department of Botany, University of Wyoming, 1000 East University Ave, Laramie, WY 82071, USA
[d] Landcare Research, Gerald St, Lincoln 7608, New Zealand
[e] INRA, UR Eco-Innov, F-78850 Thiverval-Grignon, France

ARTICLE INFO

Keywords:
Field edge
Landscape
Model
Agroecology
Weed
Cropping system
Agri-environmental measure
FlorSys

ABSTRACT

Weeds are harmful for crop production but are crucial for biodiversity in agricultural landscapes. Two contrasting strategies exist for reconciling these ecosystem services: landsharing, where crop production and biodiversity are maximised in individual fields, or landsparing, where some fields or habitats are assigned for biodiversity conservation while the remaining fields aim to maximise production. The objective of the present study was to evaluate these two strategies in silico, based on a case study with maize-based cropping systems including genetically modified varieties that allow the use of the highly efficient herbicide glyphosate in crops. The virtual-field model FlorSys simulates multi-species weed floras and their impact on crop production and biodiversity depending on cropping systems and pedoclimate. It was scaled up to the landscape level by simulating several fields in parallel, including semi-natural habitats and integrating between-field seed dispersal depending on plant height, seed mass and dispersal mode. Three series of scenarios were simulated over 28 years and 10 weather repetitions in a small landscape consisting of four 3-ha fields in Aquitaine (South-Western France): (1) landsharing scenarios based on a single diverse rotation (soybean/maize/wheat/maize), with different crop patterns in the landscape, (2) landsparing scenarios with varying proportions (ranging from 0 to 100%) of contrasting cropping systems in the landscape, either cropping system aiming to maximise biodiversity or one aiming to maximise production, and (3) landsparing scenarios including permanent grass strips (10% of each field). The landsharing scenario combining fields aiming to maximise crop production with either fields aiming to maximise biodiversity (25% of landscape) or grass strips (10% of landscape) were best, resulting in high crop production and medium biodiversity at the landscape scale. Landsharing scenarios always produced less biodiversity and less production. When more crops and cropping systems were grown each year in the landscape, the weed impact on production and biodiversity was higher and more stable over the years. These results are case-specific; new simulations and rules are needed for different types of cropping systems, landscapes and pedoclimates, and the performance of the best solutions should be tested in field studies.

1. Introduction

Enhancing biodiversity whilst improving agricultural productivity is a key goal for many European farming systems. Weeds are harmful for crop production (Oerke, 2006) but are the most important component of wild plant diversity in agricultural landscapes. They can also be a valuable food resource for other components of biodiversity (Marshall et al., 2003; Petit et al., 2011). Past studies have attempted to design strategies that reconcile crop production and biodiversity (or environmental impacts) within individual field, i.e. landsharing (Davis et al., 2012; Mézière et al., 2015a). Landsparing is another strategy where whole fields or habitats are assigned for biodiversity conservation within the agriculture landscape while the remaining fields aim to maximise production.

The advantages of landsparing vs. landsharing have been studied mostly for fauna (e.g. birds, beetles) or greenhouse gas emissions. These studies have generally been outside Europe, and over short timescales, focused on single functions or services (e.g. biodiversity) and rarely

* Corresponding author at: INRA, UMR1347 Agroécologie, BP 86510, 17 rue Sully, 21065 Dijon Cedex, France.
E-mail address: Nathalie.Colbach@inra.fr (N. Colbach).

http://dx.doi.org/10.1016/j.agee.2017.09.005
Received 27 September 2016; Received in revised form 18 August 2017; Accepted 6 September 2017
Available online 07 October 2017
0167-8809/

monitored crop production (see review by Kremen, 2015). The few studies investigating plants usually compare contrasting types of land use, e.g. arable systems, pastures and forests (Egan and Mortensen, 2012), focus on semi-natural habitats such as grass and flower strips set up by farmers in response to agro-environmental schemes (Marshall and Moonen, 2002), or try to determine the optimal proportion of cultivated land to reconcile crop production and biodiversity conservation (Makowski et al., 2007). However, several studies, whether at the field (Davis et al., 2012; Mézière et al., 2015a) or the landscape scale (Hyvönen and Huusela-Veistola, 2008; Temme and Verburg, 2011), demonstrated that weed dynamics cannot be understood and predicted without considering detailed cultural practices. The landscape scale might also be more pertinent for assessing weed dynamics and reconciling antagonistic weed-mediated functions. Indeed, weed seeds disperse in space by natural vectors (Colbach and Sache, 2001; Flores-Moreno et al., 2013) as well as agricultural machinery (Hodkinson and Thompson, 1997; Humston et al., 2005; Petit et al., 2012) or cars (Ansong and Pickering, 2013). As a result, weeds respond to landscape characteristics in addition to microhabitat characteristics (Petit et al., 2011; Alignier et al., 2012).

Consequently, our overall aim is to evaluate the costs and benefits of landsharing vs. landsparing on wild plant diversity and crop production in European temperature farming systems.

The question of what works best, landsparing or landsharing, for reconciling crop production and weed-mediated biodiversity is essential in the case of techniques that are highly efficient in controlling weeds, e.g. crops resistant to non-selective herbicides such as glyphosate (Firbank and Forcella, 2000). Genetically-modified (GM) herbicide-resistant (HR) crops aim to provide farmers with a more efficient and simpler tool to control their weeds, which is illustrated by the rapid and wide adoption of glyphosate-resistant soybean in the USA (Cerdeira and Duke, 2006). The potential adverse effects on biodiversity equally apply to varieties made resistant to more efficient herbicides (e.g. acetolactate synthase inhibitor herbicides) through traditional plant breeding or spontaneous mutations. Thus, the second objective of the present study was to investigate whether we can benefit from highly weed-suppressing techniques such as HR crops without hampering farmland biodiversity and to define at what spatial scale the trade-off between benefits and biodiversity would be optimal.

Long-term spatio-temporal processes depending on multiple factors are notoriously difficult to study in experiments or even field and landscape surveys (Fortin et al., 2003). Models are often preferred because they allow to test more systems at the long-term and with true replication (Parysow and Gertner, 1997; Colbach, 2009) and allow insights into the processes that govern flora and fauna dynamics (Schröder and Seppelt, 2006). Simulations are indeed essential to identify the most interesting options which can then be implemented in experiments where only a few situations can be tested because of cost and time constraints (Cordeau et al., 2015). Moreover, simulation studies allow us to evaluate novel techniques ex ante, which is crucial for the highly sensitive question of GM crops. Consequently, we chose to evaluate the potential of landsparing vs. landsharing for reconciling production and biodiversity with simulation models. These are increasingly used in very different farming disciplines, in research (Groot et al., 2012; Jeuffroy et al., 2014) but also for supporting farming decision taking (Pannell et al., 2004) and policy making (Colbach et al., 2006).

To date, few studies have modelled arable weeds at the landscape scale. Their representation of agricultural practices is often very simplistic and they only consider one species. These singular species are usually very harmful for crop production such as grass weeds (Gonzalez-Andujar and Perry, 1995; Page et al., 2006; Gonzalez-Diaz et al., 2015), herbicide-resistant weeds (Maxwell et al., 1990; Dauer et al., 2009), and GM crop volunteers (Colbach, 2009). Different modelling approaches were used, e.g. a metapopulation (Gonzalez-Andujar and Perry, 1995; Gonzalez-Diaz et al., 2015), a cellular automata framework (Wang et al., 2003), a GIS-based statistical model including geographical characteristics of the fields (Page et al., 2006), or a polygonal representation of agricultural fields (Maxwell et al., 1990; Colbach, 2009; Dauer et al., 2009). None of these models specifically represented cropping systems. The crop type directly determines the set of parameters, with at best a possibility to vary herbicide use intensity. Key practices such as tillage are missing in these models. The only exception is the GeneSys model (Colbach, 2009) but this predicts the dynamics and genetics of a crop volunteer.

Weed dynamics models focusing on cropping system effects are more frequent at the field scale (see reviews by Holst et al., 2007; Freckleton and Stephens, 2009; Colbach, 2010) but only a few of these are multispecific and only one explicitly targets weed benefits and harmfulness for crop production and biodiversity (Colbach et al., 2014a). This model (called FlorSys) simulates the effects of cultural operations and weather on soil, crop and weed seeds and plants at a daily time step; it assesses weed impact via a series of indicators of weed harmfulness for crop production and weed contribution to biodiversity. Consequently, rather than completing existing landscape models to account for crop production, we chose to scale up FlorSys (Colbach et al., 2014a) from the field to the landscape scale, by simulating several fields in parallel and by introducing seed dispersal and semi-natural habitats.

In summary, the specific objectives of the present study were (1) to propose a simulation-based method for evaluating landsharing vs. landsparing at the landscape level with multiple weed species, and (2) to apply the method to the particular case of glyphosate-based cropping systems, by testing in silico contrasting landsharing and landsparing scenarios in terms of weed impact on crop production and biodiversity in European temperature conditions. The tested scenarios included associations of cropping systems only, as well as associations including semi-natural habitats, attempting to move from cropping systems to agroecological systems (Duru et al., 2015; Lescourret et al., 2015).

2. Material and methods

2.1. A short presentation of FlorSys

2.1.1. Weed and crop life-cycle

FlorSys is a virtual field where cropping systems can be experimentally tested and a large range of crop, weed and environmental measures estimated. The structure of FlorSys is presented in detail in previous papers (Gardarin et al., 2012; Munier-Jolain et al., 2013; Munier-Jolain et al., 2014; Colbach et al., 2014b; Colbach et al., 2014c; Mézière et al., 2015b). Only a short summary is given here. Further details can be found in Section A of the Supplementary material online.

The input variables of FlorSys consist of (1) a description of the simulated field (daily weather, latitude and soil characteristics); (2) all the simulated cultural operations in the field, with dates, tools and options; and (3) the initial weed seed bank which is chosen to reflect the regional species pool. These input variables influence the annual life-cycle which applies to annual weeds and crops, with a daily time-step. Pre-emergent stages (surviving, dormant and germinating seeds, emerging seedlings) are driven by soil structure, temperature and water potential. Post-emergent processes (e.g. photosynthesis, respiration, growth, etiolation) are driven by light availability and air temperature. Crop:weed canopy is simulated with a 3D, individual-based representation. At plant maturity, weed seeds are added to the soil seed bank; crop grains are harvested to determine crop yield. Life-cycle processes also depend on management practices, in interaction with weather and soil conditions on the day the operations are carried out. To reduce the simulation time greatly lengthened by the 3D canopy representation, usually only a representative field sample (e.g. 6 m × 3 m) is simulated. Total seed and plant populations of the simulated field are then deduced by multiplying simulated densities by the ratio of the total vs. simulated field areas.