Agricultural Systems 149 (2016) 40–53

Contents lists available at ScienceDirect

Agricultural Systems

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

Profiling farming management strategies with contrasting pesticide use in France

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ARTICLE INFO

Article history:
Received 8 April 2016
Received in revised form 2 August 2016
Accepted 7 August 2016
Available online 15 August 2016

Keywords:
Pesticide use
Pesticide reduction
Farm network
Regression tree
Production situation
Management strategy

ABSTRACT

Reducing pesticide use in agriculture is a major challenge to improve sustainability of cropping systems. It is critical to identify effective integrated farming strategies able to decrease substantially pesticide use. This study is based on a unique French national network of 1012 arable commercial farms involved in a pesticide reduction program. These farms displayed contrasting levels of pesticide use, and covered a large diversity of environmental characteristics and farming practices. Our objective was to identify profiles of management strategies showing contrasting pesticide use levels in France. Two categories of factors potentially related to pesticide use were considered successively, namely factors describing production situations and factors describing management strategies. Regression tree methods were applied to the dataset to identify combinations of factors associated with low vs. high pesticide use levels. Results showed that, among the factors describing production situations, the presence of livestock, climate conditions, and to a lesser extent soil characteristics were able to discriminate groups of farms with contrasting pesticide use levels. Among the factors describing management strategies, the crop sequence, the crop diversity, the pesticide spraying techniques, and soil tillage were frequently selected for discriminating farms characterised by low vs. high pesticide use levels, whereas specific factors such as mechanical weeding, crop cultivars and sowing dates were related with pesticide use in some production situations only. Across production situations, several contrasting strategies led to low levels of pesticide use. Besides, within each considered production situation, different strategies appeared associated with low levels of pesticide use. Our results reveal that a large diversity of strategies exists for controlling pests, weeds and diseases without high levels of pesticide use.

1. Introduction

A substantial reduction of pesticide use is required to make agriculture more sustainable (Matson et al., 1997). This objective will be achieved only if farming practices go through major changes in order to enhance the bio-physical regulation of pests (Wezel et al., 2014). In this context, the concept of Integrated Pest Management (IPM) emphasises the combination of a wide range of technical levers alternative to chemicals for pest management in order to achieve sustainable economic benefits with the lowest risk to human health and the environment (Glass, 1975; Barzman et al., 2015; Lamichhane et al., 2015). Many experiments based on IPM principles were carried out to assess potentialities of innovative approaches able to reduce pesticide use through the combination of alternative management options (e.g. Reganold et al., 2001; Deike et al., 2008; Chikowo et al., 2009). Innovative cropping systems tested in these experiments were based both on preventive (e.g. diversified crop rotation, soil tillage strategy including false seed bed techniques) and curative measures (e.g. biocontrol, mechanical weeding), with the objective to diversify perturbation factors of pests lifecycle (Barzman et al., 2015). However, economic, environmental and social performances of cropping systems are strongly influenced by bio-physical (e.g. climatic conditions, soil composition) and socio-economic (e.g. presence of livestock, outlets for industrial crops) local drivers (Bürger et al., 2012; Aouadi et al., 2015). These local drivers are not easy to control by farmers, and their combination defined a so-called concept of production situation (PS) (Aubertot and Robin, 2013). In classical experimental approaches, experimental outputs partly reflect the constraints and opportunities defined by the specific PS, and the generic value of conclusions may be questioned (Doré et al., 2011). Results from one experiment in one site might be valid only in those production contexts that are close to the experimental production context. The IPM-based management strategies that are likely to best reconcile the various aspects of agricultural sustainability might be different from one site to one another, but all combinations

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http://dx.doi.org/10.1016/j.agsy.2016.08.005
0308-521X/

of management options cannot be tested experimentally in all types of PS. As a complementary approach, networks of commercial farms may create the opportunity to study real farms showing a diversity of farming managements in line with the constraints and opportunities coming from a wide range of PSs.

Launched in 2008, the French national plan Ecophyto has set a target of a 50% decrease in pesticide use, initially planned to be reached by the year 2018 (French Ministry of Agriculture and Fisheries, 2008). However, French agriculture is today far from achieving this goal, and the end of the initial plan was recently postponed to 2025. To guide farmers and help them to adopt more sustainable practices, one pillar of this plan relies on DEPHY, a national network of commercial demonstration farms. This network involves two thousand farms, committed since 2011 in a reduction of their pesticide reliance. It covers a large diversity of production systems, ranging from arable cropping to vineyards, orchards, vegetables, etc. DEPHY is based on 200 farm advisors, who both provide a local guidance to the farmers, and collect data. It produces a dataset for enhancing knowledge on the management measures that make it possible to reduce pesticide use. Each arable farm from the network is a based on a specific management strategy (MS) characterised by both the crop sequence and the sets of management techniques applied to the different crops.

Our hypotheses were: (i) MSs leading to low pesticide use are based on combinations of several management measures, (ii) those MSs are different across PSs, and (iii) low pesticide use levels could be reached through different MSs within a given PS. To test these hypotheses, we carried out a detailed analysis of pesticide use variability with the Classification and Regression Tree method (CART), able to handle complex interactions between explanatory variables. The method was previously used to study cropping systems. For example, it proved to be useful to understand how soil characteristics and crop management may explain variability in maize productivity in farms from western Kenya (Tittonell et al., 2008). Here we used biophysical, socio-economic, and management data collected over arable farms located in France. Regression trees were fitted to the dataset to identify combinations of factors discriminating farms according to their level of pesticide use, i.e. related to low vs. high pesticide use. This approach was first applied to pesticide use averaged at the farm level, and then separately to pesticide use for two major crops, namely winter wheat and maize, in order (i) to highlight indirect links between the composition of the crops sequence and pesticide use in wheat and maize, respectively, and (ii) to highlight further technical options related to pesticide use on these crops.

2. Material and methods

2.1. Data collected on the DEPHY demonstration farm network

In this study we focused on the 1012 non-organic arable farms of the DEPHY farm network, accounting for >66,000 ha of arable area. For each farm, the main MS was described in detail between 2009 and 2011. We collected data describing both the PS and the MS. A review of the scientific literature was performed to identify a set of variables which may potentially affect pesticide use intensity.

2.2. TFI

We used the Treatment Frequency Index (TFI) to quantify pesticide use in each farm. The TFI (OECD, 2001) estimates the number of reference doses applied, for each pesticide, per hectare and per crop season. TFI was expressed at the farm level by averaging the crop TFI according to the proportion of each crop in the crop sequence:

$$\mathrm{TFI} = \sum_{j=1}^{k} \left(\sum_{i=1}^{n} \frac{\mathrm{D}_i \cdot S_i}{Dh_i \cdot S_t} \right) \cdot \omega_j$$

where D_i, Dh_i, and S_i, $i = 1, \ldots, n$ are, respectively, the applied dose, the reference dose, and the treated surface area for the n spraying operations; S_t is the total plot area; and ω_j, $j = 1, \ldots, k$ are the proportions of each j crop in the crop sequence. The applied dose and the reference dose were both expressed for a given commercial product (that possibly contains several active ingredients). As recommended by the French Ministry of Agriculture for TFI computation, we selected the reference dose as the lowest of the different registered doses specified across the various possible targeted pests for each pesticide-crop combination. All registered doses came from the E-phy online database provided by the French Ministry of Agriculture (Ephy website, 2014). TFI is an indicator that summarizes dependence on pesticides, which should be distinguished from the environmental impact of pesticides.

2.3. Variables characterizing production situations

We identified 46 variables describing PSs. According to the literature, these variables could have some effects on crop development or pest pressure and therefore on pesticide use (details provided in Supplementary data Table S1). Some of these variables corresponded to bio-physical characteristics and described the effects of climate and soil or field characteristics at each site. Maximum yields achieved on winter wheat and maize during the previous years on each farm were used as a proxy for yield potentials, i.e., maximum yield values that could be obtained in a farm given its soil and climate characteristics. Climate variables were derived from the SAFRAN database (Quintana-Seguí et al., 2008) providing ten years (2002 − 2011) of daily national climatic data at the scale of 8 × 8 km spatial meshes. The other variables were related to the socio-economic background and described, for instance, the access to particular local market opportunities for agricultural outputs with high added-value (e.g. farms within the sugar beet catchment area of sugar factories, etc.), the combination of arable crops with livestock breeding in mixed farms, or the average field distance to the farm holding. Farms were considered to be associated with livestock as soon as the crop sequence included at least one self-consumed crop to feed livestock present on the farm.

2.4. Variables describing management strategies

278 variables were defined to describe the MSs (details provided in Supplementary data Table S1). These variables characterised crop rotation composition and diversity, soil tillage type and intensity, weed management strategy, pesticide spraying strategy and fertilisation rates. These variables were computed both separately for several crop species (e.g. winter wheat, maize, grassland, oilseed rape, sugar beet) and at the farm level using weighted average over the crop rotation, with weights equal to the frequencies of the crops in the crop sequence. Crop type diversity was assessed by measuring the frequency of cultivation of six different groups of species (Supplementary data Table S1). Sowing period diversity was described by measuring the frequency of occurrence of five different sowing periods over year.

2.5. Identification of combinations of variables discriminating low vs. high pesticide use

2.5.1. CART (Classification and Regression Tree)

We used a recursive partitioning approach based on the CART method (Breiman et al., 1984) to split our sample of 1012 TFI values using the PS and MS variables into sub-samples that build a regression tree explaining TFI variability. A split for a given node is a dichotomy leading to two lower nodes with contrasting TFI values. A split involves (i) the choice of the most discriminating variable among the set of explanatory variables, and (ii) the choice of the best dichotomy on the variable previously selected, so that it permits the highest reduction in the within node TFI variability. The final tree is composed of several branches, where each branch corresponds to a combination of successive splits