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Integrating simulation data from a crop model in the development of an agri-environmental indicator for soil cover in Switzerland

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ABSTRACT

Agriculture generates important impacts on the environment, which can be evaluated with agri-environmental indicators. A key element of environment protection in agriculture is the maintenance of a dense soil cover for the longest possible period. Notably, soil cover is known to diminish erosion risks and nitrate leaching. In this study, an agri-environmental indicator for soil cover is presented, which integrates data from the crop model STICS to quantify vegetation growth dynamics. Simulations were conducted with STICS for the major crops cultivated in Switzerland across several contrasting pedoclimatic situations. They were then integrated with data for crop residue cover to evaluate soil cover at the field and farm levels in the framework of a farm network survey. At the field level, for the period from the harvest of the previous crop through the harvest of the main crop, the highest soil cover was achieved by silage maize and winter barley. A high variability between fields was observed, due to the diversity of cultural practices during the period preceding the seeding of the main crops. Some crops, winter wheat in particular, showed a high number of days with insufficient soil cover (under 30%), leading to potential environmental risks. This shows the crucial need of promoting conservation agriculture principles (permanent soil cover, minimum soil disturbance, diversification of crop rotation) in arable systems to better protect the soils and the environment. The soil cover indicator presented here provided a continuous quantification of soil cover, whereas most of the currently used indicators provide qualitative or roughly quantitative results.

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1. Introduction

Agriculture involves major modifications of the environment and directly influences soil and water quality through crop rotation, tillage practices and crop management. In order to evaluate the impact of agriculture on the environment, many agri-environmental monitoring programs have been set up at the international (e.g. FAO, OECD, UN, EU) and national levels (Giupponi and Carpani, 2006; Piorr, 2003; Yli-Viikari et al., 2007), including Switzerland (FOAG, 2015). In this context, sets of indicators have been developed, aimed at evaluating and quantifying the main pressures exerted by agriculture on natural resources. A decrease in the impact of agriculture on the environment is a crucial issue for a more sustainable development. This objective is at the core of conservation agriculture, which is being promoted more and more as an alternative to intensive and environmentally damaging conventional agriculture (Lahmar, 2010; Scopel et al., 2013). Conservation agriculture is based on three main principles: 1. minimization of soil disturbance, 2. diversification of crops in rotation and association, and 3. improvement of soil cover (Scopel et al., 2013). Among these elements, soil cover plays a recognized role for environment protection, through diminished wind and water erosion, limited leaching and run-off, increased weed control and improved soil fertility (Blanchart et al., 2006; Dabney, 1998; Duran and Rodriguez, 2008; Gilley et al., 1986a,b; Thorup-Kristensen et al., 2003; Quinton et al., 1997; van Donk, 2010). A minimum threshold value of 30% soil cover is generally recommended in order to achieve this environmental protection role (FAO, 2015).

Soil cover embraces the cover offered by the crop itself as well as that provided by the crop residues from the preceding crop. Several factors influence soil cover and have to be taken into account

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Table 1
Crops simulated with STICS and corresponding seeding dates.

	Seeding date		
	Early	Standard	Late
Winter wheat	01.10	01.11	01.12
Winter rapeseed	15.08	01.09	15.09
Winter barley	15.09	01.10	10.10
Winter pea	01.10	15.10	30.10
Silage maize	15.04	10.05	15.05
Grain maize	15.04	10.05	15.05
Sugar beet	15.03	01.04	15.04
Potato	10.04	20.04	01.05
Soybean	20.04	01.05	15.05
Sunflower	10.04	20.04	01.05

Table 2
Soil textures used for the simulations and corresponding soil classification according to the USDA and Swiss texture triangles.

USDA classification	Swiss classification	Clay	Silt	Sand
Clay	Silty clay	45%	25%	30%
Sandy clay loam	Loamy	25%	25%	50%
Sandy loam	Sandy loam	8%	25%	67%

in the development of an accurate soil cover indicator. The crop type determines the amount of live cover as well as the amount of residues after harvest. Residue management and tillage practices influence the proportion of residues incorporated in the soil after each intervention. The pedoclimatic conditions affect the degradation of residues as well as the growth of crops.

Soil cover indicators are generally included in monitoring programs such as that set up by the OECD or EU (Piorr, 2003). However, most existing indicators rely on very simplistic assumptions in order to evaluate soil cover (e.g. Bechini and Castoldi, 2009; Eurostat, 2015; OECD, 2001). They usually count the number of days the soil is covered during a year, the soil being fully covered or not at all, without offering any possibility of giving intermediate values. Moreover, they often assume that soil is completely covered by vegetation from crop seeding to harvest without taking into account the dynamics of crop growth, nor the winter pause. A great improvement in these indicators was achieved with the indicator developed for Canadian agriculture (Huffman et al., 2000, 2012, 2015; Lobb et al., 2007). The central idea of this indicator is to evaluate the number of days an area is covered during one year, taking into account that soil cover may continuously vary between 0 and 100%.

However, a huge quantity of data needs to be obtained for the computation of such a soil cover indicator. Firstly, concerning the cover provided by residues, information is needed about the degree of soil cover after harvest, the incorporation rate of residues during tillage interventions, and the decomposition rate of residues. Secondly, for the cover provided by crop vegetation, information is needed about emergence time, growth speed and vegetation spatial spread. All this data could potentially be measured directly in the field, but the computation of an indicator at large spatial scales renders direct measurements almost impossible. In the absence of field data, technical literature can be used as a source of general information on soil cover by residues. In contrast, data on the dynamics of soil cover by growing crops is linked to pedoclimatic conditions and thus better assessed regionally. For this reason, an alternative approach is to integrate simulation data from a crop model, taking into account regional variations in crop development dynamics and phenology. Crop models such as STICS (Brisson et al., 1998, 2002, 2003) simulate crop growth day by day, taking into account real daily meteorological data, as well as principal soil characteristics, for a large variety of crops. This model has been validated as a performing crop model in the literature (e.g. Beaudoin et al., 2008; Constantin et al., 2012; Coucheney et al., 2015; Palosuo et al., 2011).

This study presents the first quantitative estimation of the soil cover for arable crop rotations at the field and farm levels in Switzerland through the development of a soil cover indicator. Using the model STICS, the dynamics of the main field crops for various Swiss climatic regions and soils were simulated, with the aim of quantifying distinctive values of soil cover. This new approach is expected to produce a large variation of specific results in substitution to constant soil cover data and rough estimations used in current methodologies. These simulations were then integrated with estimations of residue cover for the period before the seeding of the main crop in order to quantify the soil cover for a full crop sequence. This indicator was tested using a database collected by the Swiss agri-environmental data network (SAEDN). It also aimed at evaluating the suitability of the method to explore more thoroughly the differences in soil cover between arable crops, the effects of cropping techniques on soil cover at field scale and the replication of these elements at the farm level.

This article presents first the crop soil cover dynamics simulated with the STICS model and second the methodology, application and quantitative evaluation of the soil cover indicator in the framework of the farm network database.

2. Materials and methods

2.1. Soil cover indicator principle

The computation principle of the indicator is based on the Canadian soil cover indicator (Huffman et al., 2000, 2012, 2015; Lobb et al., 2007). The unit of computation is the agricultural field. The indicator is expressed as the total number of soil cover days (SCD) achieved over a given period, or as the corresponding average soil cover (ASC). The number of SCD is obtained by summing, over the whole period, the daily soil cover value, which can vary continuously between 0% and 100%. One SCD corresponds thus to a full cover (100%) during one day or to a partial cover during more days, e.g. 2 days at 50%, 10 days at 10%. The soil cover takes into account two main components: the residues left from the preceding crop and the dynamic growth of vegetation. For both elements, databases have been built to provide reference values for different agricultural situations.

2.2. Data collection

2.2.1. Cover by residues

The degree of cover by residues depends on the amount of residues after harvest, the decomposition rate of these residues as well as the residue incorporation rate by tillage operations. Quantitative information about these three aspects was obtained from technical literature.

Soil cover after harvest for different crop types were collected from US extension services documentation (Shelton et al., 1995; Iowa State University Extension, 2009).

The residue decomposition function follows a negative exponential as a function of initial residue mass and time (Steiner et al., 1999; Stott et al., 1995), and soil cover (*SC*) is exponentially linked to residue mass (*M*) (Steiner et al., 2000; Stott et al., 1995).

$$M_t = M_0 \times \exp(-K_D \times \Delta t)$$

$$SC = 1 - \exp(-K_m \times M)$$

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