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Precision conservation meets precision agriculture: A case study from southern Ontario

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ABSTRACT

Meeting future food demands for 9 billion people in the next 30 years will require either agricultural expansion or intensification to increase production. However, agriculture is already a major driver of biodiversity loss, as well as freshwater withdrawals, nutrient inputs, and greenhouse gasses, among other pressing environmental issues. In this paper, we look for solutions to this production-conservation challenge at the subfield scale. We use precision agriculture yield data from three farms in Southern Ontario and convert them into "profit maps" that show which regions of a field have management costs that exceed the market value of the commodities produced. We analyse the profit of three farms over time and identify areas that consistently show low or negative profit and thus constitute a compelling case for taking these areas out of production. We find, for example, that up to 14% of farmland can result in money loss and even more than 50% of the land might still not meet minimum revenue expectations. Further, we assess the economic feasibility of conservation strategies on these set-aside lands and find that investing in environmental benefits (even minimally) can often times be inexpensive when compared with economic losses due to failed harvests. We argue that profit mapping can serve as a management tool for farmers that will allow them to identify optimal crop areas, optimize nutrient inputs, plan for ecological intensification, and avoid economic loss all while providing ecosystem services at the local scale.

1. Introduction

The expected human population of 9.7 billion by 2050 will demand a 70% increase in food production (Holt-Giménez and Altieri, 2013; Fraser et al., 2016). Agriculture already produces enough calories for the current population; however, due to systemic problems linked with poverty, approximately 800 million people are undernourished and 2 billion people experience micronutrient deficiency (FAO et al., 2018). On top of this, agriculture is a critical economic activity for the livelihood of 40% of the world's population and represents 30% of the gross domestic product in low-income countries (Ramankutty et al., 2018). As a consequence, there will be a demand for the further expansion or intensification of agricultural production (De Marsily and Abarca-Del-Rio, 2016; Rizvi et al., 2018).

The expansion of agricultural and urban areas has already led to the conversion of 43% of the Earth's land (Barnosky et al., 2011) and is currently the major cause of habitat loss and biodiversity decline (Laurance et al., 2014). Agriculture alone is responsible for the conversion of 70% of grasslands, 50% of savannahs, 45% of temperate deciduous forests, and 27% of tropical forests (Foley et al., 2011; Pagnutti et al., 2013). Industrial agriculture —alongside mining and energy infrastructure —results is the loss of 5 million ha of forests every year (Curtis et al., 2018). Additionally, agriculture demands 70% of freshwater withdrawals and has already pushed two thirds of the global rivers' basins beyond their capacity to buffer nutrient inputs (German et al., 2017). Agricultural and grazing practices combined are responsible for the soil degradation of 23% of the world's arable land (Grunwald et al., 2011), which in turn results in the demand of more land conversion (Laurance et al., 2014). As for greenhouse gasses, agriculture accounts for up to 30% of emissions, including those originating from ruminant animals, land use change, fertilizers use, and fossil fuels (Garnett, 2011).

Approaches for biodiversity conservation have been shifting over time as a result of how relationships between people and nature are viewed (Mace, 2014). Currently, in agricultural systems, part of the conservation debate revolves around the "land sharing / land sparing"

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dilemma (Green et al., 2005). Land sparing refers to strictly protect some land while intensively farming on smaller land footprints, while land sharing intends to establish less areas for strict biodiversity conservation but to carefully utilize larger land footprints (Durán et al., 2014; Kremen, 2015). Although there is evidence to support both alternatives and the debate is ongoing (Kremen, 2015), land sparing is more commonly adopted around the world (Mertz and Mertens, 2017). Nonetheless, in agricultural systems, authors consider than when small and dispersed fragments of land are spared, land-sharing landscapes are created (Kremen, 2015).

Another approach for conservation in agricultural lands has focused on protecting ecosystem services —benefits that people obtain from ecosystems. Agriculture depends on services such as nutrient and water cycling, the maintenance of soil quality, and pest regulation, and in turn provides value services such as crop production, fibres, and energy (Schipanski et al., 2014). However, under appropriate management practices, agricultural lands can also provide non-value ecosystem services —air quality, soil carbon storage, habitat for biodiversity, and landscape aesthetics (Rapidel et al., 2015). For example, crop rotations —as opposed to monocultures— can increase soil carbon and total nitrogen, and soil microbial biomass carbon and nitrogen (McDaniel et al., 2014). Also, pest-tolerant and resistant cultivars can reduce overreliance on pesticides and thus their runoff into natural systems (Barzman et al., 2015). Moreover, cover crops can reduce soil erosion and compaction, better soil structural and hydraulic properties, and supress weed growth (McDaniel et al., 2014; Blanco-Canqui et al., 2015). The interdependence of humans and nature is such, that global ecosystem services have been valued at US$125 trillion/year (Costanza et al., 2014). Acknowledging this economic value can improve the effective management of ecosystems and guide the design of economic incentives such as payment for ecosystem services (Costanza et al., 2017).

Given the spatial heterogeneity of agricultural landscapes (e.g. soil type, slope, nutrient levels, moisture content), the optimization of production and conservation in agroecosystems requires spatially explicit analyses and technologies. The term ‘precision conservation’, has emerged as a way of describing approaches that aim to conserve soil and water in agricultural and natural lands, based on a combination of spatial technologies (such as global positioning systems, remote sensing, or geographic information systems) and procedures (such as map analysis, surface modeling, spatial data mining) (Berry et al., 2005). Precision conservation is also related to ‘precision agriculture’, which is defined as “techniques that monitor and optimize production processes … thereby conceivably increasing yields and outputs and improving the efficiency and effectiveness of inputs” (Fraser, 2018). This includes utilizing technological innovations including ‘robot farmers’, self-driving tractors, software codes, computational models, and the creation and storage of big data on agricultural practices, productivity and yields, and biophysical properties of the land (Fraser, 2018). Environmentally speaking, precision agriculture has been successfully applied to avoid excessive chemical inputs in soil, reduce carbon footprint in field operations, reduce herbicide and pesticide use, and monitor plant health (Schrijver et al., 2016). From an economic standpoint, precision agriculture contributes to food safety by better predicting on the quality and quantity of agricultural products, reducing expenses, and monitoring the food chain (Schrijver et al., 2016). In addition, precision agriculture can help plan for the “sustainable intensification” of agricultural production, as increases in yields should be strategically sought through a context- and location-specific approach (Garnett et al., 2013).

One particular use of precision agriculture, profit mapping, has gained momentum as a tool to motivate producers to set aside unprofitable lands for conservation for addressing areas that are prone to environmental risks such as soil erosion (Muth, 2014). Brandes et al. (2016), in a similar analysis, identified “hotspots” for “potential management change”. In this paper, we use precision agriculture data to demonstrate how precision agriculture technologies can be used to increase environmental benefits in Southern Ontario's agricultural lands by putting agricultural production and alternate management scenarios on the same economic footing. We show the use of precision agriculture yield crop data as a way of developing high-resolution profit maps of farms. We then use these maps to identify areas, at the subfield scale, that consistently show low or negative profit and thus could be set aside for conservation and increased ecosystem services. We also assess the economic feasibility of eight strategies that could promote biodiversity and ecosystem services on such low profit areas. We work under two hypotheses: a) areas of consistent low or negative profit can be detected by the use of precision agriculture and profit mapping, and b) investing in conservation strategies on these low profit areas can be more economically feasible than investing (and losing money) in agriculture.

2. Methods

2.1. Study area

The province of Ontario accounts for 25% of Canada's farmland and 20% of the country's gross farm receipts (Statistics Canada, 2017). In Ontario, 50,000 farms spread over 5 million ha (OMAFRA 2017). Soybeans and corn find their largest production in this province, accounting for almost 60 and 50% of their cultivated area, respectively. To enhance biodiversity, interrupt pest cycles, and increase nutrient efficiency, soybean and corn are usually rotated with wheat (Statistics Canada, 2017). We worked on three farms —namely A (82.15 ha), B (23.07 ha), and C (29.95 ha)— that have been on a soybean, corn, and wheat rotation for the past 10 years. The farms are located in Wellington County (between 80° and 81°W, and 43°30′ and 44°N), near the cities of Fergus and Rockwood. Although in this County the farm average size is 56.25 ha, farmers are likely responsible for grater extents of land, as most of them work their own farms and rent additional land (Cummings et al., 2006). In this area, the surface deposits are in its majority of glacial origin and formed the parent material from which soils have developed (typically loamy soils within the study region). The terrain also presents many low broad oval hills with smooth slopes characteristic of drumlins. Overall, the soils are well drained and suitable for agriculture (Hoffman et al., 1963; Chapman and Putnam, 1984).

2.2. Calculation of profitability

We obtained precision agriculture data from the farm owners, who conduct yield and plant population monitoring and use Geographic Positioning Systems (GPS) technologies to produce high-resolution maps of their farm yield. The data we used consisted on yield measurements (bushels acre^{-1}) obtained from harvest yield monitors. These monitors use optical sensors to measure yield and are installed on combines. Here, we converted yield data to kg ha^{-1} assuming corn weighs 25.40 kg bushel^{-1} (OMAFRA, 2018a) whereas soybeans and wheat weigh 27.70 kg bushel^{-1} (OMAFRA 2018b and 2018c). Yield data points were spaced out between 1.5 and 10 m, resulting in an average density of 808 yield points ha^{-1} for farm A, 919 yield points ha^{-1} for farm B, and 755 yield points ha^{-1} for farm C.

We used four years (2013–16) of data for farm A, five years for farm B (2011, 2013–16), and nine years (2001, 2003–04, 2006, 2010–11, 2014–16) for farm C. To estimate profitability, we consulted the Ontario Ministry for Agriculture, Food, and Rural Affairs' (OMAFRA) provincial estimates of field crop budgets and grain market prices for each year. Estimates of field crop budgets included the cost of growing each crop based on operating (e.g. seeds, fertilizers, herbicides, tractor and machine expenses, crop insurance, labour work) and overhead (e.g. depreciation of machinery, interest on investment) expenses per acre (OMAFRA, 2001–2016). Grain market prices consisted on the provincial average market price per bushel (OMAFRA, 2018d). We