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Pollinators, pests and soil properties interactively shape oilseed rape yield

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Abstract

Pollination, pest control, and soil properties are well known to affect agricultural production. These factors might interactively shape crop yield, but most studies focus on only one of these factors at a time. We used 15 winter oilseed rape (*Brassica napus* L.) fields in Sweden to study how variation among fields in pollinator visitation rates, pollen beetle attack rates and soil properties (soil texture, pH and organic carbon) interactively determined crop yield. The fields were embedded in a landscape gradient with contrasting proportions of arable and semi-natural land. In general, pollinator visitation and pest levels were negatively correlated and varied independently of soil properties. This may reflect that above- and below-ground processes react at landscape and local spatial scales, respectively. The above-ground biotic interactions and below-ground abiotic factors interactively affected crop yield. Pollinator visitation was the strongest predictor positively associated with yield. High soil pH also benefited yield, but only at lower pest loads. Surprisingly, high pest loads increased the pollinator benefits for yield. Implementing management plans at different spatial scales can create synergies among above- and below-ground ecosystem processes, but both scales are needed given that different processes react at different spatial scales.

Zusammenfassung

Bestäubung, Schädlingskontrolle und Bodeneigenschaften beeinflussen die Agrarproduktion. Diese Faktoren könnten interagierend den Ernteertrag beeinflussen, aber die meisten Studien konzentrieren sich auf nur einen Faktor. Wir untersuchten auf 15 Winterrapsfeldern (*Brassica napus L.*) in Schweden, wie die von Feld zu Feld variierenden Bestäuberbesuchsraten, Rapsglanzkäfer-Befallsraten und Bodeneigenschaften (Bodentextur, pH, organischer Kohlenstoff) wechselwirkend den Ertrag bestimmten. Die Felder repräsentierten einen Landschaftsgradienten mit unterschiedlichen Anteilen von Agrarflächen und naturnahen Arealen. Allgemein waren Bestäuberbesuch und Schädlingsbefall negativ miteinander korreliert, und sie variierten unabhängig von den Bodeneigenschaften. Dies könnte anzeigen, dass oberirdische Prozesse und Prozesse im Boden auf der Landschaftsebene bzw. der lokalen Ebene reagieren. Die oberirdischen biotischen Interaktionen und die abiotischen Bodenfaktoren beeinflussten wechselwirkend den Ertrag. Der Bestäuberbesuch war der stärkste positiv mit dem Ertrag verknüpfte Faktor.

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Ein hoher pH-Wert begünstigte ebenfalls den Ertrag, aber nur bei geringem Schädlingsbefall. Überraschenderweise, steigerte hoher Schädlingsbefall die positive Wirkung des Bestäuberbesuchs auf den Ertrag. Das Aufstellen von Bewirtschaftungsplänen auf unterschiedlichen räumlichen Skalen kann Synergien zwischen oberirdischen und unterirdischen Ökosystemprozessen freisetzen, aber beide Skalen werden benötigt, da unterschiedliche Prozesse auf unterschiedlichen Skalen reagieren.

Keywords: Ecosystem services; Above- and below-ground processes; Pollination; Pollen beetles; Oilseed rape; Soil organic carbon; pH

Introduction

Future agriculture needs to be productive to sustain the increasing human population, while conserving biodiversity and the environment. A suggested solution is to stabilize or increase crop yields by maximizing the use of ecosystem services provided by biodiversity, thereby decreasing the dependence on external inputs of agrochemicals in agriculture (Bommarco, Kleijn, & Potts 2013). For this, we need to resolve how different biotic and abiotic processes interactively shape yield, something that is poorly understood.

Crop pollination is a key ecosystem service that supports crop yield quantity (Garibaldi et al. 2013) and quality (Bartomeus et al. 2014) in three quarters of all crop species (Klein et al. 2007). In contrast, herbivory by pest insects typically reduces yields in all major crops by 5–15% on average (Oerke & Dehne 2004), and in individual cases yield losses can be far higher (e.g., pollen beetle yield losses in oilseed rape fields may reach up to 80%, Nilsson 1987). In addition, several soil properties affect crop production. There is solid evidence from agricultural trials showing that soil texture is associated with water retention (Rawls, Gish, & Brakensiek 1991). Soil organic carbon (SOC) increases the stability of several soil properties, such as increasing the soil cation-exchange capacity (Campbell 1978; Johnston, Poulton, & Coleman 2009; Lal 2010, 2011). Soil pH is closely linked to biological activity of below-ground soil communities and positively related to nutrient availability and soil fertility (Foth & Ellis 1997), which may translate to higher crop yield (Dick 1992; Barszczak, Barszczak, & Foy 1993).

Despite the widely acknowledged importance of pollination, pest herbivory and soil properties for shaping yield, the information we have on the joint effects of these factors on yields is fragmentary at best. Hence processes above- and below-ground are generally studied in isolation, and its contribution to plant growth and crop yield can only be estimated if we consider them to be additive. However, this assumption has been challenged in small-scale experiments showing complex interactions between both compartments (Van der Putten, Vet, Harvey, & Wäckers 2001; Bezemer et al. 2005; Barber, Adler, Theis, Hazzard, & Kiers 2012). Above- and below-ground communities can be powerful mutual drivers, with both positive and negative feedbacks among them (Strauss & Irwin 2004; Wardle et al. 2004). Such interactions remain unexplored for larger spatial scales.

For instance, pollination has most often been studied as a context-independent process, but recent findings suggest that pollination success and resulting crop yield are linked to other factors such as fruit predation, irrigation or fertilization (Bos et al. 2007; Boreux, Kushalappa, Vaast, & Ghazoul 2013; Lundin, Smith, Rundlöf, & Bommarco 2013; Classen et al. 2014; Klein, Hendrix, Clough, Scofield, & Kremen 2015; Motzke, Tscharntke, Wanger, & Klein 2014; Wielgoss et al. 2015). For example, Lundin et al. (2013) experimentally showed that pollination and pest control of a seed predator interact synergistically. The combined effect of these ecosystem services on the yield was higher than the sum of the isolated services. Local crop management can also interact synergistically with pollination. There is recent evidence that irrigation positively affects the net benefit to the plant from pollinators in two contrasting crops, coffee and almond (Boreux et al. 2013; Klein et al. 2015). More generally, it is expected that below-ground soil properties, as well as related ecosystem services provided by soil organisms (Wagg, Bender, Widmer, & van der Heijden 2014), change water retention and nutrient assimilation, and hence should interplay with above-ground biotic interactions such as pollination and pest damage in deciding the yield (e.g., Williams, Birkhofer, & Hedlund 2014).

Most evidence about interactive effects on yield from above- and below-ground processes comes from experimental studies (e.g., Barber et al. 2012; Lundin et al. 2013). We lack detailed data on how crop yield is affected by multiple processes at the scales at which crop cultivation takes place–in the arable field and in the surrounding landscape (but see Boreux et al. 2013). For example, pollinators and natural enemies to crop pests are both affected by landscape composition at scales up to several kilometers (Shackelford et al. 2013), whereas soil properties are mostly affected locally by management of the individual arable field. Hence, policy-relevant assessments of ecosystem services in agricultural landscapes cannot rely on the simple assumption that a certain land-use results in a given service supply. Not only local field management, but also the composition of the surrounding landscape is an important determinant of biodiversity and ecosystem services (Gabriel et al. 2010). Attempts to maximize the production of a single ecosystem service can result in substantial declines in the provision of