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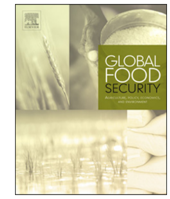

Exploiting ecosystem services in agriculture for increased food security

Riccardo Bommarco[a,*], Giulia Vico[b], Sara Hallin[c]

[a] Swedish University of Agricultural Sciences, Department of Ecology, 75007 Uppsala, Sweden
[b] Swedish University of Agricultural Sciences, Department of Crop Production Ecology, 75007 Uppsala, Sweden
[c] Swedish University of Agricultural Sciences, Department of Forest Mycology and Plant Pathology, 75007 Uppsala, Sweden

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ABSTRACT

Despite contributing to economy and food security, Ecosystem Services (ES) are still not fully exploited in agriculture. Instead, external inputs have been used to boost yields, while exacting costs on public goods. Ecological intensification capitalizes on ecosystem services to enhance and stabilize production and reduce the need for external inputs, while sparing the environment. Of particular relevance are biodiversity-based ES connected to soil fertility, pest control and pollination. Ecological intensification is applicable in all regions, but for food security purposes, particular attention should be dedicated to implement it as ecological enhancement in regions with wide yield gaps, coinciding with poor food security. Diversified cropping system show promise to create win-win situations. Knowledge on ecology and socio-economy of ES will be needed, and agricultural research and innovation need to heed to resource use efficiency, production stability, minimal environmental impact, buffering of extreme events and adaptation to local conditions.

1. Food security through ecological intensification

Society needs to ensure local and global food security, i.e., availability, access and utilization of food, and stability of the former three (FAO, 2014). To support food availability, crop production has over the past decades been increased by abandoning traditional practices supporting ecosystem services (ES) and replacing them with external inputs (Tilman et al., 2001). This approach has so far been successful in meeting ever increasing global demands for food, feed and fibre, but has also exacted environmental costs. For example, leached inputs have degraded the environment, and put public goods, such as clean water, at risk. Two of the most severe effects of intensive agriculture is the large impact on Earth's biogeochemical and hydrological cycles, which have caused a cascade of effects contributing to climate change, degradation of aquatic ecosystems and human health problems (e.g. Galloway et al., 2008; Gordon et al., 2008; Bouwman et al., 2013). Even in the presence of sufficient food availability, these effects can negatively impact food security by curtailing access both to food due to reduced incomes and to food utilization from reduced availability of drinking water.

Agriculture is, furthermore, the primary cause of terrestrial biodiversity loss (Maxwell et al., 2016), mainly from agricultural expansion but also as a result of intensification (Kehoe et al., 2017). Biodiversity loss is, in turn, a major driver of ecosystem change (Hooper et al., 2012). Intensive agriculture can also negatively impact crop production itself. Grain yields have levelled off or even declined in key regions (Ray et al., 2012), partly because of cropping with few crops in short rotations (Bennett et al., 2012) and poor management of ES linked to soil fertility and plant protection (e.g. Settle et al., 1996; Foley et al., 2005). Even the mere possibility for agriculture is threatened. Soil erosion caused by intensive agriculture is a severe problem in several areas (Pimentel et al., 1995) and climate change is expected to negatively impact crop production and its stability (Challinor et al., 2014; Lobell and Tebaldi, 2014). We thus need to modify the current approaches to ensure long-term food security, locally and globally.

Here we outline how the exploitation and active management of ES can form a basis for achieving high output, low input farming that produces stably and is adaptable under changing conditions. Such stable and productive, but lean, cropping is vital for farmers with poor food security and few resources. Of particular relevance are the ES delivered by biodiversity, as many beneficial organisms and biological functions are often overlooked or poorly understood, inadequately maintained, and therefore not fully exploited for sufficient and stable crop yields. The use of biodiversity-based ES can increase the effectiveness of invested and locally available resources, thereby enhancing and stabilising yields at minimal economic cost. Further, we envisage that the approach will minimize pressure on the environment, human health and public goods that historically have been degraded in the quest for higher crop yields. We argue that to increase food security most effectively, ecologically intensified cropping systems should be

* Corresponding author.
E-mail address: Riccardo.Bommarco@slu.se (R. Bommarco).

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developed and implemented in the regions where yield gaps are currently large and food security is typically low.

2. Biodiversity and ecosystem services on farmland

Given the climatic conditions on a farm and the crop genetics available, there are two main components that determine crop yield: the capture of resources to the plant and losses to pests. Both are greatly affected by living organisms below and above ground, referred to as functional biodiversity. Farmed land harbours a wealth of biota apart from the obvious crops and weeds in the fields and field borders. In the soil dwells a daunting number of species and individuals of bacteria, fungi, arthropods, protozoa, nematodes and earthworms. Hundreds of species of insects, spiders, mites and mammals fly, climb and crawl above ground. Parts of the biota are well known pests that reduce crop yields, but many, possibly most, perform activities that are beneficial for agriculture. Resource capture by the crop is enhanced by decomposers that release nutrients, and enhance soil fertility and structure. Mutualistic organisms such as nitrogen fixing bacteria, pollinators and mycorrhizal fungi feed resources that form yield (Bommarco et al., 2013). Crop losses are reduced by microbial antagonists and predatory arthropods that regulate diseases and pests, and contribute with enormous economic values (Losey and Vaughan, 2006).

3. Ecological intensification of agriculture with ecosystem services

Ecological intensification in farming - i.e., the enhancement of productivity or replacement of anthropogenic inputs by enhancing ES - has been suggested as a strategy to overcome the combined challenges of feeding the world while sparing the environment and public goods. The concept was promoted by Cassman (1999), who focused on how enhancing soil fertility in combination with technological advances can increase crop yields in high-producing areas through improved capture and reduced leakage of resources. The concept has since been expanded to include other ES, such as biological pest control, soil services and crop pollination (Bommarco et al., 2013).

Examples of how production and environmental goals can be met with ecological intensification are emerging. Setting aside arable land for wildlife habitat creation rendered ES that increased yield per unit area so that the overall crop production from the field was maintained (Pywell et al., 2015). Agricultural intensification without biodiversity loss was observed in grasslands, although conservation and production could not be maximized simultaneously at the landscape level (Simons and Weisser, 2017). In managed forest ecosystems, a negative effect of biodiversity loss on forest productivity and the benefits from the transition of monocultures to mixed-species stands in forestry practices were recently demonstrated (Liang et al., 2016). Ecological intensification in agriculture is now moving towards explicitly considering and capitalizing on the organisms whose activities prevent yield losses, and enhance soil fertility and resource capture (e.g. Kennedy et al., 2013, Bender et al., 2016). A recent review shows a predominance of win-win situations from ecologically intensified cropping, as compared with conventional farming, in terms of maintaining or increasing both yields and public goods (Garbach et al., 2017). Nevertheless, more efforts are needed to identify underpinning mechanisms and design farming systems that result in such win-win multi-functional outcomes.

Ecological intensification has potential to contribute to long-term food security globally, by reducing i) the yield gap - i.e., the difference between what is actually produced on farms in a region and the potential primary production, given the climatic and edaphic conditions at that location, and with no losses to pests (van Ittersum and Rabbinge, 1997), and ii) the resource use efficiency gap - i.e., enhancing the output in relation to the input (van Noordwijk and Brussaard, 2014). It has been suggested, but not yet verified, that ecological intensification supports a more stable and resilient crop production (Bommarco et al., 2013). This might be as important for long-term food security as for yield levels in the face of future, more variable, climatic conditions (Challinor et al., 2014; Lobell and Tebaldi, 2014). For example, if a severe drought event such as the Dust Bowl crisis in the 1930's should occur today, it would result in a 40% loss in maize and soy yield and a 30% decline in wheat yield in the U.S. due to low resilience (Glotter and Elliot, 2016). Diverse agricultural systems emerge as more resilient to climate variability and climate change (Altieri and Nicholls, 2017), but the mechanisms remain largely unexplored (Gil et al., 2017; Di Falco, 2012b). Promoting resilience will likely require moving away from input-intensive agriculture and rethinking the current model of how we manage agroecosystems.

4. Contrasting goals depending on local food security

Ecological intensification would need to be implemented with somewhat contrasting (but not mutually exclusive) goals depending on the food security situation and production level in a specific region. In high-producing regions, which typically depend on high levels of external inputs, the yield gap is small, but the environmental impacts are often large. In this case, the focus should be to reduce negative impacts on the environment and public goods rather than towards further closing the yield gap. Of special concern is to mitigate climate change by exploiting ES that minimize greenhouse gas emissions and increase carbon sequestration (Philippot and Hallin, 2011). For example, there are research-based solutions for curbing nitrogen-related greenhouse gas emissions in China without adventuring food security (Zhang et al., 2013). The main challenge in high-producing regions would be to, at least partly, replace the reliance on external inputs, by restoring ES to maintain reasonably high and stable crop production levels (Bommarco et al., 2013).

Globally, food security will be effectively strengthened if crop production is increased in regions with large yield gaps (van Ittersum et al., 2013; Lobell et al., 2009, www.yieldgap.org), where food security is typically poor (Mueller et al., 2012). In these regions, efforts to enhance food security shall therefore primarily be directed towards increasing yield level and, importantly, crop yield stability. The food security of poor consumers is largely affected by price shifts as they spend a large proportion of their income on food (Hertela et al., 2010). Increasing and stabilizing crop production by closing the yield gap locally in these areas will reduce the dependency on the larger market, create a basis for a vital local economy, and increase food security (FAO, 2011). Means to close yield gaps that were used in the Green Revolution are likely to be inadequate and potentially counterproductive in these regions and have been shown to be ineffective and often poorly adapted to the biophysical and socio-economic conditions in, for instance, sub-Saharan Africa (Tittonell and Griffin, 2013). Green Revolution intensification based on mineral fertilizers and improved genetics of a crop (e.g. maize) do raise yields (Denning et al., 2009), but is costly and require subsidies to farmers that put substantial pressure on government spending and allocation in a low income country (Chirwa and Dorward, 2013). In contrast, diverse agriculture including multiple crops and enhanced biodiversity-based functions that increase the effectiveness of moderate amounts of mineral fertilizers, includes legumes that fixate nitrogen, has been demonstrated to increase farmers profitability, match farmers' preferences and enhance food security in sub-Saharan Africa (Snapp et al., 2010). Ecological intensification through ecological enhancement to close yield gaps, emerges as a more suitable and very effective alternative.

5. Underutilised or poorly understood ecosystem services for food security

To enhance food security, ecological intensification needs to exploit several ES, among which some are currently underutilized or not fully