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Policies for ecological intensification of crop production

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Abstract

Ecological intensification aims to increase crop productivity by enhancing biodiversity and associated ecosystem services, while minimizing the use of synthetic inputs and cropland expansion. Policies to promote ecological intensification have emerged in different countries, but they are still scarce and vary widely across regions. Here we propose ten policy targets that governments can follow for ecological intensification.

The search for a new agricultural paradigm

Globally, an intense search for new agricultural paradigms is on, to correct the failings of current systems. Many, including policymakers, consumers, scientists, and farmers, are calling for a transition from conventional to ecological intensification [1,2]. The aim is to maintain or increase long-term agricultural productivity, while reducing reliance on synthetic inputs and cropland expansion, through effective management of ecosystem services provided by biodiversity [1–3]. Resource use efficiency is sought not only by more precise use of synthetic inputs (without necessarily achieving "zero" use of synthetic inputs such as in organic agriculture), but also by working with co-existing biota (e.g., plant microbiome, detrivores, pollinators, natural enemies) to improve plant water and nutrient uptake, stress tolerance, pollination, and defenses against pests and diseases. Such ecological intensification describes a process rather than an endpoint and could be considered a necessary pathway for more comprehensive objectives of agroecology, food security, and sustainable intensification (see [3] for a more detailed definition and history of these terms). Policies to support ecological intensification are being implemented in some countries, but they are usually scarce or inadequate and vary widely across regions. Here we propose ten science-based policy targets that provide a framework for the implementation of ecological intensification (Box 1, Figure 1) and for scientific research aiming to integrate biological and political perspectives (see Table S1 for knowledge gaps). According to the definition adopted here [1–3], targets 1 and 2 are core to ecological intensification, while targets 3-8 are effective ways to achieve targets 1 and 2. Ecological intensification also provides multiple benefits beyond agricultural productivity (target 9), but requires participatory action, knowledge and training (target 10). Our list is not exhaustive and, except for targets 9 and 10, we focus on the biophysical aspects of ecological intensification. As we demonstrate below, ecological intensification embraces practices that can be applied by both small- and large-scale farmers [1,4].

Box 1 to be inserted around here (moved to end for type-setters)

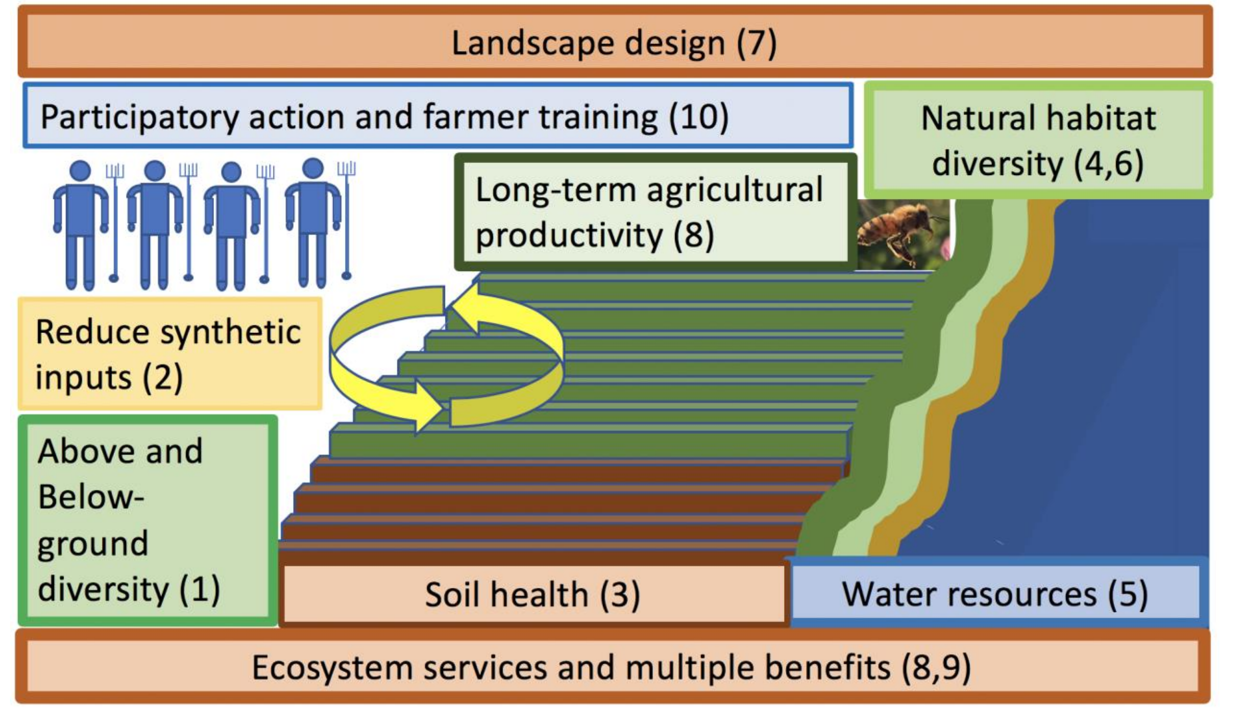

Figure 1. Science-based policy targets for ecological intensification of crop production should consider multiple dimensions. Policies that support one target can often have positive impacts

on other dimensions of the agro-ecological landscape. All targets (see Box 1) are important but, depending on the context, a few should be emphasized.

Underpinning ecological intensification

Farms with greater below- and above-ground species diversity (**target 1**, Box 1) promote ecosystem services and can increase agricultural productivity [4,5] (detailed references for all targets are provided in Table S1). Indeed, wild and crop plant richness support diverse animal communities, both below- and above-ground [5], as they offer a wider range of feeding resources (Figure S1). Common measures include the establishment of hedgerows, floral or prairie strips, or leaving a proportion of land fallow. Some initiatives such as agri-environment schemes in EU policy, have offered financial incentives for farmers that adopt these measures. In some developing countries where field sizes are small and it is less possible to allocate land to non-crop purposes, farmers have innovated by growing flowering crops that are attractive to beneficial insects in the boundaries of crops that are less attractive [6]. For example, growing nectar-producing plants around rice fields has been shown to enhance predators and parasitoids of rice pests, reduce pest populations, enhance detritivores, reduce insecticide applications by 70%, increase grain yields by 5%, and deliver an economic advantage of 7.5% in Thailand, China and Vietnam [6].

Reducing the use of synthetic inputs (**target 2**) such as plastic films, agrochemicals, and non-renewable energy minimizes negative externalities, including greenhouse gases, plastic waste, resistant weeds, biodiversity loss, water and food pollution, and can even increase agricultural productivity and (or) farmers' profit [3,6,7]. Current strategies to reduce the negative impact of agriculture-produced plastic waste, such as the European Strategy for plastics in a Circular Economy, focus on recycling or the development of new bio-based materials (Table S1). All over the world, examples of excessive use of agrochemicals include those (a) in West Africa, where pesticide use levels generate widespread risks to terrestrial and aquatic wildlife [8]; (b) in France, where it was estimated that total pesticide use could be reduced by 42% without any negative effects on both productivity and profitability in 59% of the surveyed farms [9]; and (c) in China, where about 20.9 million small-scale farmers increased average yields (maize, rice, and wheat) by 10.8–11.5%, while reducing application of synthetic sources of nitrogen by 15–18%, through an integrated soil-crop system management framework [1]. Common measures to reduce the use of synthetic agrochemicals are to implement precision agriculture, crop rotation, and integrated pest management (Table S1). Multiple policies have supported measures to reduce pesticide use, mostly focusing on direct and lethal toxic effects (e.g. on pollinating bees). For example, recently (May 2018), the European Union have agreed to completely ban the use of three neonicotinoid insecticides in outdoor farms. The Government of Vanuatu has built into its National Sustainable Development plan the phasing out of synthetic inputs in its agriculture, while the Danish Government aims to double its organically cultivated area nationally by 2020 (Table S1). Such organic commitments are seen by these Governments as having multiple advantages, including benefits to tourism and fostering greater use of local knowledge on traditional crops and foods (see target 9).

Supporting ecological intensification

Soil health (**target 3**) is linked with key biological and physical processes (carbon transformations, nutrient cycles, soil structure maintenance, and the regulation of pests and diseases) that support agricultural productivity [10] (Table S1). However, soil organic matter and below-ground biodiversity (both proxies for soil health) are declining in many agricultural systems [5,10,11]. Practices such as crop diversification, including legumes into rotations, efficient use of organic fertilizers, and reducing tillage can prevent or reverse such trends [5] (Table S1). In the Indian state of Andhra Pradesh, the Zero Budget Natural Farming initiative (incorporated into government policy at the state level) seeks to help farmers build soil fertility and transition from using chemical to organic inputs. In the USA, California's Healthy Soils Initiative has five main goals to enhance soil health: to protect and restore soil organic matter; to identify sustainable and integrated financing opportunities; to provide research, education and technical support; to increase governmental efficiencies on public and private lands; and to promote inter-agency coordination (Table S1).

Conservation or restoration of natural or semi-natural areas in agricultural landscapes (**target 4**) can enhance diversity of beneficial organisms by providing resources that are not available in crop fields, such as nesting sites or food (Table S1). It can be achieved through incentives such as voluntary agri-environment schemes, or mandatory Ecological Focus Areas in Europe, or the Conservation Reserve Program (CRP), Conservation Stewardship Program (CSP) and Environmental Quality Incentives Programs (EQIP) in the USA. In Brazil, set asides or "legal reserves" are mandatory. A portion of each farm must focus on the conservation or restoration of ecological processes and biodiversity, protection of the native fauna and flora, and sustainable use of natural resources (such as rubber extraction or Brazil nut harvesting in the Amazon forest). The size of the "legal reserves" varies as follows: 80% of the farm when it is in the forest area of the Legal Amazon biome; 35% of the farm when it is in the Cerrado area of the Legal Amazon biome; and 20% percent of the farm in all the other regions of Brazil.

Protecting and efficiently using water resources (**target 5**) can enhance agricultural productivity and minimizes negative externalities. Common measures include engineering solutions to prevent droughts or floods, using drought-resistant crops, enhancing soil health (target 3), and protecting natural or semi-natural areas (target 4). Riparian zones are at the intersection of water resources, biodiversity, and agriculture and their importance has been recognized by the Water Resources Commission of Ghana in developing the Riparian Buffer Zone Policy (although implementation has been lacking; Table S1). In the main row crop region of the USA, the incorporation of prairie strips directly contributed to improved biodiversity and was able to reduce total water runoff from catchments by 37%, resulting in retention of 20 times more soil [12]. This practice can be supported, in part, by farmer cost-share under the USDA Conservation Reserve Program (CRP). In our view, policies which promote the strategic restoration of riparian zones should be able to provide disproportionate environmental benefits (relative to the investment), especially in the most productive cropping systems.

Enhancing habitat diversity (**target 6**) can create agroecosystems that are capable of self-regulation, including resisting pest and disease infestations. Measures include enhancing the variety of flowering crops, providing different resources that can be exploited across time and space by beneficial organisms (Table S1). However, agricultural landscapes are increasingly under monocultures, mainly of a few cereal and oil crop species, which compromise habitat diversity [13]. Some countries where monocultures prevail are promoting new initiatives, such as the Strategic Development Plan of the Agricultural Sector (PSDSA) of Benin, to create more heterogeneous agroecosystems through crop diversification (Table S1). A recent law proposal (December 2017) for *minimum budgets for biodiversity in agricultural landscapes* presented to the Argentinean Senate, states that at least four different habitats should be established per 200 ha, each covering a minimum of 5 ha with natural areas making up one of the four units.

The benefits of ecological intensification are context dependent [14] and creating habitat to support beneficial organisms must consider the surrounding landscape (**target 7**). For example, the need for species richness to deliver sufficient services increases with spatial scale as the number of crop types accumulates, as demonstrated for crop pollination [15]. For large-scale farms, there are many examples of extensive networks of flowering strips between production units (Figure 2), with multiple benefits for both crop pollination and biotic pest regulation [7]. To support healthy populations that provide ecosystem services to all farms in a region, agricultural policies in the EU promote green infrastructures that facilitate connectivity across crop dominated landscapes (Table S1). Such strategic, landscape-scale conservation demands coordinated actions that can be beyond the means of individual land managers [16]. Support can be provided for farmers to work together, such as in the Countryside Stewardship facilitation fund in England, which supports coordinated action by “farm clusters” (Table S1).

Figure 2. Recently planted habitat for natural enemies and pollinators incorporated into a landscape design at a large holding in California’s San Joaquin Valley (USA). This 2.3-mile corridor of hedgerows and meadow was planted as part of the Xerces Society’s Bee Better Certified™ program. Photo: Peter Allbright, Woolf Farming Co.

Compared with conventional inputs such as pesticide or synthetic fertilizer, ecologically intensive practices can take time to deliver results, thus requiring their evaluation over the long-term (**target 8**). Habitat interventions such as floral strips for pollinators work by building up populations over seasons [7]. These can then increase agricultural productivity, returning initial investments in management [17]. Similarly, benefits derived from good soil structure and healthy below-ground communities accrue slowly (Table S1). The stability and resilience of agricultural productivity derived from greater species richness are only realized over time frames that include cropping seasons with adverse weather, extreme climatic events, or pest outbreaks (Table S1). Policies that consider these longer time frames include the financial support in the EU for establishment and maintenance of agro-forestry. Also, the establishment of risk management insurance schemes, parallel to those that exist as part of climate smart agriculture [18], could cover crop loses in years when the ecological-intensive practice has not delivered as expected. Being aware that solving current agricultural threats requires long-term and sustained actions, the National

Landcare Program in Australia was conceived for covering a period of over ten years (2014-2023; Table S1).

Delivering ecological intensification

Policies for ecological intensification should consider (and balance) multiple costs and benefits, as well as synergies and trade-offs among benefits (**target 9**) [3]. Examples of benefits beyond crop yield include improved human health from reduced pesticide use, as in many countries foods are contaminated with pesticide residues (Table S1); increased production of nutritious food in areas with greater agricultural diversity [19]; and conservation of cultural heritages or traditions, such as the symbolic meaning and use of different species and the diverse landscapes preferred by people in which to live. As people have different preferences, a variety of ecosystem services are necessary to produce an environment contributing to high value for all. Therefore, policies should account for a plurality of views (legitimacy) and be relevant to the needs (e.g. income or social identity) of the stakeholders affected (salience). For example, the UK Countryside Stewardship Scheme provides support for maintaining areas of traditional water meadows and orchards for their cultural and conservation value. These habitats are also important for species which deliver ecosystem services to agriculture (Table S1). In Bolivia, the Mother Earth Law supports sustainable development, respecting the balance between human life and the natural environment, and prioritizing the rights and knowledge of the country's majority indigenous population (Table S1).

Successful examples of adoption of ecological intensification have commonly involved farmer training, participatory action research, and building of social capital (**target 10**) (see examples in Table S1 and [20]). Conventional intensification provides a simple package of practices based on large monocultures and synthetic inputs [3]. Such a model has its roots in the industrial revolution when humans were less than 15% of the current population and environmental externalities of production systems were not so evident. In contrast, ecological intensification is knowledge-intensive and emerges as an urgent need in a world with more than 7 billion people. Examples include the Global Farmer Field School Platform, run by the Food and Agricultural Organization of the United Nations, providing support and technical advice to Governments and national advisory services (Table S1). Effective implementation will also depend on the involvement of large food companies, that could have an enormous influence on farmer practices through setting environmental targets for the agricultural products they buy. Such environmental-friendly products are being increasingly demanded by consumers all over the world.

Overall, given the importance of a wide spectrum of organisms as ecosystem service providers, policies that target the protection of whole biotic communities in agricultural ecosystems, rather than just one or a few species are expected to be more efficient in meeting growing demands for produce while maintaining multi-functional agricultural landscapes. Such measures do not necessarily compete with farmers' profit [9]. They can even be established in areas with lower yield potential but, sometimes, higher conservation value such as river margins or areas with steep slopes. Indeed, in many cases agricultural productivity and (or) profit increase as a result of enhanced ecosystem services [3,4,17]. In Table S1 we provide 24 examples of our ten policy targets across at least 14 countries and the European Union (27 Member States). These examples illustrate the diversity of possible implementation routes. The options available to a particular group of policymakers depend on the political, historic, and environmental context, and also on how the target is interpreted, in terms of its precise objective, scale, and magnitude. Given the variety of possible implementation routes and outcomes, it is important that policies implemented in support of ecological intensification include clearly stated objectives, with measurable targets, against which each policy can regularly be evaluated. In our view, the most supportive policies for ecological intensification will consider agriculture as a system that addresses national food security and provides wellbeing to rural populations, through investment in ecological infrastructure and knowledge management.

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Supplemental Information

Supplemental information associated with this article can be found, in the online version, at (...)

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Box 1. Science-based policy targets for ecological intensification

1. Enhance below- and above-ground species diversity
2. Reduce synthetic inputs
3. Enhance soil health
4. Maintain or restore natural and semi-natural areas
5. Protect and efficiently use water resources
6. Enhance habitat diversity
7. Integrate practices into a landscape design
8. Evaluate agricultural productivity and ecosystem services over the long-term
9. Consider multiple benefits
10. Facilitate participatory action and farmer training