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RESEARCH ARTICLE

# Towards the sustainable intensification of agriculture—a systems approach to policy formulation

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**Abstract** The sustainable intensification of agriculture involves providing sufficient food and other ecosystem services without going beyond the limits of the earth's system. Here a project management approach is suggested to help guide agricultural policy to deliver these objectives. The first step is to agree measurable outcomes, integrating formal policy goals with the often much less formal and much more diverse goals of individual farmers. The second step is to assess current performance. Ideally, this will involve the use of farm-scale metrics that can feed into process models that address social and environmental domains as well as production issues that can be benchmarked and upscaled to landscape and country. Some policy goals can be delivered by supporting ad hoc interventions, while others require the redesign of the farming system. A pipeline of research, knowledge and capacity building is needed to ensure the continuous increase in farm performance. System models can help prioritise policy interventions. Formal optimization of land use is only appropriate if the policy goals are clear, and the constraints understood. In practice, the best approach may depend on the scale of action that is required, and on the amount of resource and infrastructure available to generate, implement and manage policy.

**Keywords** agricultural policy, ecosystem services, indicators of sustainable intensification, knowledge exchange, land use optimization

## 1 Introduction

The challenge for global agriculture is well understood; food production needs to increase during the coming decades while reducing agriculture's negative environmental impact[1]. While there is still potential arable land that could be brought back into production or has not been cropped[2], it is widely accepted that targets can only be met by increasing the productivity of land already in production. There is clearly a need to produce more food with less input per unit land, but the challenge is to design policy to deliver this objective.

The process of getting more food from less has been termed sustainable intensification (SI)[1]. The initial focus of SI research was on improving the resource use efficiency of agriculture. The classic study along these lines showed that it was possible to increase yields, increase profitability, reduce inputs and reduce pollution at a very large scale across China by engaging farmers to adopt the input recommendations of a decision support system[3]. This approach sought to match input levels to local needs, so can be regarded as a very large scale example of precision agriculture. Notably, it was successful because of the attention given to engagement with farmers (see also Zhang et al.[4]).

But delivering truly sustainable agriculture is not simply a case of managing resource use efficiency. Agriculture needs to provide for human needs without going beyond the functioning limits of the earth's system. Agriculture needs to stay within a safe and just operating space[5]. This means that foodstuffs are produced that meet the dietary needs of people without exceeding the planetary boundaries that frame the earth system's capacity for environmental homeostasis[6]. Agriculture needs to deliver sustainable diets[7], but it must also deliver social and economic needs[8,9]. The challenge is to reconcile these larger-scale, policy objectives with the desires and requirements of the individual farmers.

This paper explores an approach to implementing agricultural policy to deliver farming that is truly sustainable. The approach is to adopt a formal project management approach to the issue. First, measurable goals are agreed; current performance assessed; the current agrifood system assessed, potential interventions are considered and implemented, and performance reviewed.

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## 2 The approach

### 2.1 Agree measurable outcomes

Agriculture is expected to deliver a range of ecosystem services and other societal benefits. These outcomes can be grouped into domains, which comprise productivity, social, human, economic and environmental[10,11]. At the farm level, the goals represent those aspects of the production system that are meaningful to the farm and its major stakeholders. Key goals typically involve the production of goods and services that allow the farm to continue as an economically viable unit. These goals are rarely formal quantitative targets, and often involve a degree of optimization and trade-off between different goals at the farm household level[12]. For example, there may be a balance between contemporary production and the potential for future production of food and other ecosystem services[13], especially in the soil[14].

However, policy objectives require a more formal, integrative approach. At global scales, the objectives are to keep within the safe and just operating space, while delivering sustainable diets[7]. These global objectives have been down-scaled to national levels through the UN Sustainable Development Goals (UNSDGs)[15] alongside other social and environmental commitments. Therefore, a key policy challenge is to have farm-scale goals that are both meaningful and achievable and, once integrated across landscapes and regions, deliver national, and hence global, targets.

A diversity of land management strategies may be required to account for ecosystem services that are delivered at the landscape and catchment scale[16] and to include some of the socioeconomic, health and livelihood issues important for wider communities[17–19]. Landscapes can be designed to enhance biodiversity and multifunctionality[20], and can integrate or separate farming and biodiversity according to context[21]. There may be a strong spatial disparity of ecosystem service production and demand[22–25]. The balance of foods generated by markets alone may not provide sustainable diets for all[7], Not surprisingly, large scale urbanization is associated with the loss of ecosystem services, not least food production[26]. Yet developing usable targets for such complex systems is difficult. One reason is that any analysis is highly scale dependent; areas dominated by the delivery of particular ecosystem service (e.g., crop production) may seem to perform poorly in other services at a landscape scale but may be vital at meeting population needs at national and regional scales. The impacts of the resulting trade flows are starting to be taken into account in analyses of ecosystem service provision[27,28] and are used routinely in environmental footprinting[29,30]. There is as yet no completely integrated set of agricultural indicators that is operable from farm to national and global scales. There are real sociopolitical challenges in agreeing measurable outcomes; who sets the targets, whether they are prescriptive in some way, used to influence farmer behavior through regulation or financial support[31], or simply used as a guide to policy makers.

### 2.2 Assess current performance

The ideal measures of farm performance would allow comparisons between different farms and systems, trends over time and parameterization of appropriate models. Ideally, farm performance should be assessed using fine-scaled, disaggregated data that can be re-aggregated into high level indicators of performance, allowing flexibility in case the choice of indicators and outcomes evolves. The data should also be able to be used to parameterize key models describing processes such as crop growth and carbon budgets. Data should be freely available, subject to commercial confidentiality. Current approaches do not approach these requirements, but progress is rapid, driven both by advances in technology and reporting needs.

The major ways of assessing farm performance are surveys of farmers and other stakeholders (professionally or using some form of self-assessment), direct sensing of the farm and its environment, use of externally-sourced and pre-existing data, and the use of models.

Surveys of farmers are of course widely undertaken[10,32,33]. The challenges include potentially poor response rate, and variable quality of data available, though the increasing use of software to collate farm management information is improving the range of data that can be collected in some parts of the world. Such surveys can be complemented by more specialist field data collection[33], and can be combined with externally-sourced data including remote sensing[34]. In Europe, the main approach to assess farm performance has been a statutory farm survey to populate the Farm Accountancy Data Network (FADN)[35], as well as custom surveys (e.g., Carey et al.[36]). More recently, farm surveys have been implemented that reflect the different domains of farm performance, and can potentially be used to address progress toward UNSDGs[10]. Models have been applied to farm management data to infer environmental outcomes without specialist sensing[37,38]. The perception of performance can depend greatly upon how the data are scaled. For example, in a recent survey in the UK, performance was given per unit farm area[11], giving a very different impression compared with scaling per unit product. Care is also needed to interpret correctly differences between farming systems as well as the social and biophysical context. The interpretation of such assessments depends upon the choice and degree of integration of metrics; some authors adopt a single, integrated measure of performance (e.g, Zhao et al.[39], see also Areal et al.[40]). This approach makes comparisons simple but can lose transparency and hide the weighting of different factors. In contrast, the use of separate indicators can miss the interactions between them, especially if some of the indicators are correlated and the desire is to identify aggregations of strong performance across multiple variables[26,41,42]. Interest is growing in reducing the effort required to conduct new surveys of farmers. One approach is to apply agri-environmental models to FADN or similar preexisting data[43]. Another is to use self-reporting by the farmers themselves, either to report intentions[44] or outcomes, perhaps using farm management software. Finally, there is the rapidly developing use of remote and local sensors, coupled with data analytics, to help deliver report on current farm performance and to enable more precise management (e.g., Shoshany et al.[45] and Ojha et al.[46]). Larger scales studies rely more on national and regional databases (e.g., Chen et al.[23], Armstrong McKay et al.[47], and Firbank et al.[48]). But these data typically focus on what is easy to collect, for example farm agronomic performance, financial situation and vegetative cover.

Performance measures become the basis for action when they are compared with what could be achieved. One approach is to use benchmarking, in which a group of similar farms make their data available so that it is possible for an individual farm to compare their performance with their peers. This approach encourages the development of formal targets that are valuable to the farmers themselves, while allowing engagement with policy goals. Thus farm business survey data have been used to derive environmental impacts and N and P balances across different farm types, that can be the basis for benchmarking performance in terms of nutrient use efficiency[43,49], and crop-environment models have been integrated into a tool for estimating water footprint at the farm scale[29]. Alternatively, desired performance can be set against external criteria, for example using yield gaps[50,51]. Ideally, these should be established taking local context into account, for example by using models to forecast potential yields under improved management[52]. Aggregated performance data allow the assessment of progress toward policy goals.

## 2.3 Support ad hoc interventions

It is certainly not the case that a formal systems analysis is required before progress toward SI can be made. Indeed, a recent exercise in the UK identified a range of practices that would support SI under a wide range of conditions, suitable for policy support without precise targeting. The list included practices already in limited use, for example using stress-tolerant crop varieties, reducing tillage, incorporating organic matter, improving livestock nutrition and reseeding grasslands[3] (Table 1).

**Table 1** The spatial and temporal scales of major intended outcomes of the priority sustainable intensification practices for UK farms as listed by Dicks et al.[3]

| Practice | Time scale | | | Spatial scale | | |
|---|---|---|---|---|---|---|
| | Outcomes within a year | Managing risk | Building capital | Subfield-field | Farm | Landscape/catchment |
| Stress tolerant crop varieties | | X | | X | | |
| Reduced tillage | | | X | X | | |
| Cover crops and green manure | | | X | X | | |
| Optimise animal nutrition | X | | | | X | |
| Reseed pasture | X | | | X | | |
| Predict pest and disease outbreaks | | X | | | X | |
| Precision delivery of inputs | X | | | X | | |
| Control on-farm energy use | X | | | | X | |
| Improve marginal land for ecosystem services | | | X | | | X |
| Train farm staff in sustainability | | | X | | X | |
| Soil/plant analysis to improve efficiency of fertiliser use | X | | | X | | |
| Plant legumes | | | X | | X | |
| Use animal health diagnostics | | X | | | X | |
| Use more productive livestock | X | | | | X | |
| Controlled traffic farming | X | | | X | | |
| Adopt integrated pest management | | X | | | X | |
| Optimise grazing management | X | | | | X | |
| Benchmark environmental and financial performance | | | X | | X | |

In general, such interventions are aimed at supporting a single outcome, which may relate to production levels, production efficiency and profitability, environmental quality, consumer quality and animal welfare and societal impact. They might be implemented at field and sub-field scales, whole farm scales or regional scales, and they might be intended to provide short-term returns, support risk management or invest in the natural and agronomic capital of the farm. For example, the top priority SI practices as listed by Dicks et al.[3] are quite evenly spread between generating quick results (within a year or so) and managing risk and building social or natural capital; however, they are nearly all aimed at providing benefits at the field and farm scale (Table 1). Such analyses help can prioritize policy support for particular outcomes according to local need. However, they need to be interpreted on the basis of the desired outcome (Table 2): for example, improved soil management can provide catchment-scale benefits in terms of flood risk, which can be achieved by improved within-field soil management aimed at increasing soil carbon[53].

These interventions are aimed at improving the existing farming system. However, sometimes more radical transformation is required, involving a more fundamental redesign of the farming system, for example agroforestry

**Table 2** Identification of potential sustainable intensification practices for UK farms as listed by Dicks et al.[3] according to the desired outcome

| Practice | Desired outcome | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | More profitable production | Increased production | More resilient production | Increased soil quality | Adaptation to climate change | Mitigation of climate change | Enhanced biodiversity | Enhanced water quality | Enhanced flood control |
| Stress tolerant crop varieties | | | XX | | X | | | | |
| Reduced tillage | | | X | XX | X | X | | X | |
| Cover crops and green manure | | | X | XX | X | | | X | X |
| Optimise animal nutrition | XX | | | | | | | | |
| Reseed pasture | XX | XX | | | | | | | |
| Predict pest and disease outbreaks | XX | X | X | | | | | | |
| Precision delivery of inputs | XX | | | X | | | X | X | |
| Control on-farm energy use | XX | | | | | X | | | |
| Improve marginal land for ecosystem services | XX | | | | | | X | X | X |
| Train farm staff in sustainability | XX | | X | | X | X | X | X | X |
| Soil/plant analysis to improve efficiency of fertiliser use | XX | | | | | X | X | X | |
| Plant legumes | X | | | XX | | | | | |
| Use animal health diagnostics | X | XX | X | | | | | | |
| Use more productive livestock | | XX | | | | | | | |
| Controlled traffic farming | | X | X | XX | | | | | |
| Adopt integrated pest management | X | | XX | | | | X | | |
| Optimise grazing management | X | XX | | | | | | X | |
| Benchmark environmental and financial performance | XX | | | | | | | | |

and conservation tillage[54]. Support for knowledge sharing among farmers can be particularly effective as it builds their adaptive capacity; indeed, every large-scale example of farming system redesign reported by Pretty et al.[54] has involved building networks, trust and other forms of social capital. Farmer behavior is driven by their own knowledge and capacity, financial benefits, business model and attitudes[55]. Farmer networks[56] and demonstration farms[57] can be particularly helpful in influencing change as they provide information and influence perceived standards[58], as can benchmarking (see above). Knowledge exchange tools work best if co-designed with the users[59–61]. Strong market and regulatory signals are clearly very helpful.

## 2.4 Manage the system

To develop more integrated policies and practices to improve the performance of agriculture and food systems over time, one should understand the processes that underpin the evolution of agricultural systems. The drivers of agricultural change are environmental (particularly climate), trade, socioeconomic (in particular the availability of labor and the availability of technology) and policy (support and regulation); the challenge is to understand how they interact. For example, agricultural and environmental data in the UK were used to generate a systems model that could be used to infer potential outcomes under different scenarios reflecting broad agricultural policies in a changing climate[47] (Fig. 1). Under this very simplified model of reality, it seems as though it will prove difficult to increase yield of crops and livestock and limit environmental harm with continuous improvement in farm practices, i.e., continuous SI. The policy response to such an analysis must therefore be to focus on increasing the capacity of farmers to improve their agronomic and environmental performance. This means developing a pipeline of research, knowledge exchange and capacity building.

Having developed broad policy objectives, the challenge is to recognize which discrete actions by farmers are most appropriate, given their spatial context which accounts for both differences in demand for ecosystem services[22] and the spatial specificity needed to successfully implement larger scale policies, e.g., sustainable catchment[62] and biodiversity management[20,63]. It also comes from the constraints on the farm management practices of soils, climate, topography and transport links.

It is often suggested that the ideal approach is to develop some form of optimized land use, either at the farm[64] or landscape/catchment level[63,65,66]. There are major uncertainties in both algorithms and data behind land use simulation models (e.g., agent-based models[67], InVEST[68], and SEAMLESS[69]). Moreover, such modeling is only appropriate if the optimization goals are clear, and the constraints are appreciated. One approach to selecting appropriate policies and interventions is to check their robustness to different scenarios of socioeconomic

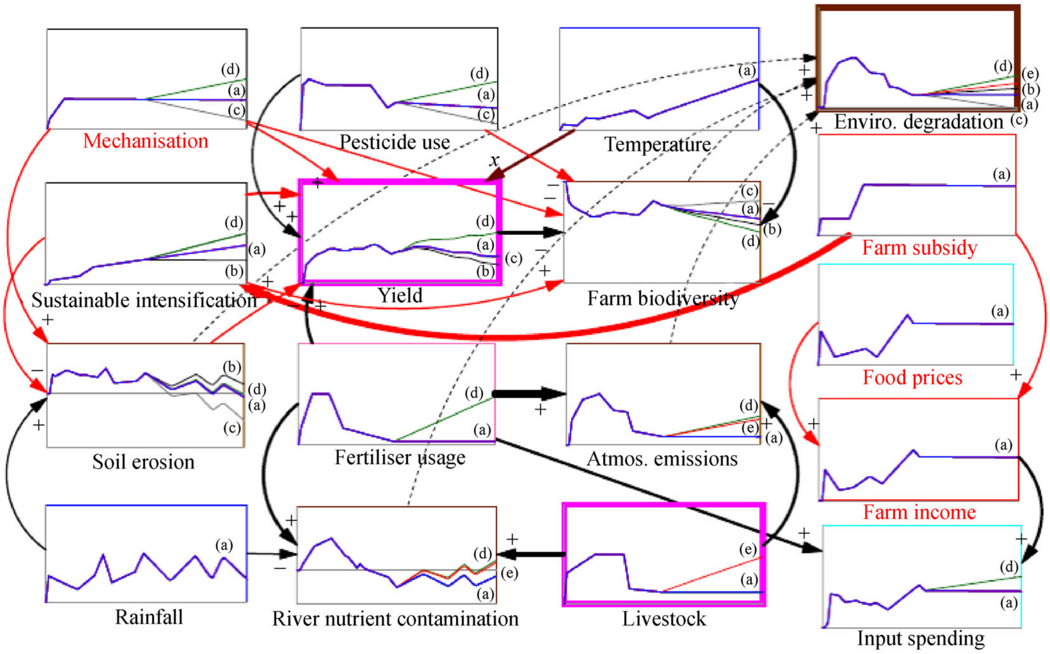

**Fig. 1** Extended simple system dynamics model for the English agroecosystem, showing how different aspects of the system can be modeled. Here simulation results are shown for 1980–2050 under different scenarios: (a) continual SI (blue lines); (b) no further SI (black); (c) biodiverse SI (gray); (d) maximize yield (green); (e) livestock intensification (red). Adapted from Armstrong McKay et al.[47], with permission from Elsevier.

and climate change[70]; those interventions which are least sensitive to the choice of scenarios are to be preferred. Implementation of such policies is challenging, but possible[71]. A second, less prescriptive, approach is to support eco-agriculture[72] or ecological intensification[73], which creates local diversity through the redesign of the farming system[54]. Finally the policy must be monitored, addressing the range of core indicators, using remote sensing[74] and/or surveys[43].

## 3 Conclusions

The provision of an agrifood system that meets human needs and is environmentally sustainable is absolutely essential in the coming decades[75], yet it requires formal planning and policy, as a truly functional agrifood system is highly unlikely to result from market forces alone[76]. Equally, the agrifood system does not exist in a vacuum, and there are a host of social, environmental and economic issues that need to be addressed for SI to be delivered successfully[77]. It may not be practical to meet all the possible demands for food and other ecosystem services, and some form of demand management may be needed.

This is a very challenging area for policy makers, as the consequences for failure are so high, while there are large uncertainties around the evidence required to inform any particular policy. It can be difficult to balance a top-down approach, in which policy seeks to target changes very precisely, and a more flexible bottom-up approach, which seeks to support overall objectives and allows local flexibility and innovation. To some extent, this choice may depend on the scale of action that is required (for example, integrated catchment management), on the amount of resource available to support policy, and the existing infrastructure to generate, implement and manage policy. Whichever approach is adopted, there is a clear need for parallel and interacting pipelines for research, capacity building and policy development for food and environmental security to be achieved.

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