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Sustainable intensification: What is its role in climate smart agriculture?

Bruce M Campbell[1,2], Philip Thornton[3], Robert Zougmoré[4], Piet van Asten[5] and Leslie Lipper[6]

The 'sustainable intensification' (SI) approach and 'climate-smart agriculture' (CSA) are highly complementary. SI is an essential means of adapting to climate change, also resulting in lower emissions per unit of output. With its emphasis on improving risk management, information flows and local institutions to support adaptive capacity, CSA provides the foundations for incentivizing and enabling intensification. But adaptation requires going beyond a narrow intensification lens to include diversified farming systems, local adaptation planning, building responsive governance systems, enhancing leadership skills, and building asset diversity. While SI and CSA are crucial for global food and nutritional security, they are only part of a multi-pronged approach, that includes reducing consumption and waste, building social safety nets, facilitating trade, and enhancing diets.

Addresses
[1] CGIAR Research Program on Climate Change, Agriculture, and Food Security (CCAFS), c/o University of Copenhagen, Rolighedsvej 21, Frederiksberg C DK-1958, Denmark
[2] International Center for Tropical Agriculture, Apartado Aéreo 6713, Cali, Colombia
[3] CCAFS, International Livestock Research Institute, PO Box 30709, Nairobi, Kenya
[4] CCAFS, International Crops Research Institute for the Semi-Arid Tropics, Bamako BP 320, Bamako, Mali
[5] International Institute of Tropical Agriculture, PO Box 7878, Upper Naguru, Kampala, Uganda
[6] Food and Agriculture Organization of the United Nations (FAO), Viale delle Terme di Caracalla, Rome 00153, Italy

Corresponding author: Campbell, Bruce M. (b.campbell@cgiar.org)

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Introduction

Agriculture faces some stiff challenges ahead. It has to address the fact that almost one billion people go to bed hungry every day, while more than two billion people will be added to the global population by 2050 [1••]. In addition, food consumption patterns are changing as the average person in the world gets richer and consumes more food and more meat. There is increased competition for land, water, energy, and other inputs into food production. Climate change poses additional challenges to agriculture, particularly in developing countries. At the same time, many current farming practices damage the environment and are a major source (19–29%) of anthropogenic greenhouse gas (GHG) emissions [2•].

While some see 'sustainable intensification' (SI) as too narrowly focused on production, or even as a contradiction in terms altogether, Garnett *et al.* [3••] make it clear that the approach should be broadly conceived. They argue that the SI approach entails increasing food production from existing farmland in ways that have lower environmental impact and which do not undermine our capacity to continue producing food in the future. Food demand needs to be met from existing agricultural land, since opening up new land for agriculture carries major environmental costs. Intensification, without the sustainability focus, has led to numerous problems around the globe [4]. SI does not mean business-as-usual food production and marginal improvements in sustainability, but rather a radical rethinking of food systems not only to reduce environmental impacts but also to enhance animal welfare and human nutrition and support rural economies and sustainable development [3••].

'Climate smart agriculture' (CSA) is another approach that has recently achieved much prominence, given the adaptation and mitigation challenges facing humanity [1••]. CSA is defined by three objectives: firstly, increasing agricultural productivity to support increased incomes, food security and development; secondly, increasing adaptive capacity at multiple levels (from farm to nation); and thirdly, decreasing greenhouse gas emissions and increasing carbon sinks. Since the relative priority of each objective varies across locations, with for example greater emphasis on productivity and adaptive capacity in low-input smallholder farming systems in least developed countries, an essential element of CSA is identifying potential synergies and trade-offs between objectives [5]. CSA integrates climate change into the planning and implementation of sustainable agriculture and informs priority-setting.

Here we examine the degree to which the SI and CSA approaches are complementary, and the degree to which they contribute to global food and nutritional security.

The arguments are supported by a selection of case studies.

Climate change adaptation

Climate change will have significant and generally negative impacts on agriculture and growth prospects in the lower latitudes [2•,6,7]. Since 1980, climate change is estimated to have reduced global yields of maize and wheat by 3.8 and 5.5%, respectively, relative to a counterfactual without rainfall and temperature trends [8]. By 2050, climate-related increases in water stress are expected to affect land areas twice the size of those areas that will experience decreased water stress [9]. Increased climate variability in the coming decades will increase the frequency and severity of floods and droughts, and will increase production risks for both croppers and livestock keepers and reduce their coping ability [10]. Climate change poses a threat to food access for both rural and urban populations, by reducing agricultural incomes, increasing risk and disrupting markets [11••]. Resource-poor producers, landless and marginalized ethnic groups are at particular risk. Negative impacts can be ameliorated through adaptation, ranging from relatively minor changes in production practices to major, transformative shifts in farming and food systems.

One of the three components of CSA is building adaptive capacity, so that farmers, service providers to farmers and key institutions have the ability to respond effectively to longer-term climate change as well as being able to manage the risks associated with increased climate variability. Actions to build adaptive capacity are diverse, but an important component entails building ecosystem services in agricultural systems that enhance resilience, through soil, water and plant nutrient management, as well as improved on-farm water storage and irrigation, access to crop varieties that are more tolerant of heat, droughts, floods and salinity, diversification of farm enterprises (including mixed crop and tree systems), and building the capacity of institutions to enhance collective action, disseminate knowledge and undertake local adaptation planning [4]. Climate information services and information related to planting dates, pest and disease control, and water availability are crucial. Managing risk may also include enhancing social safety nets and providing agricultural insurance.

Several of these actions at the heart of CSA are forms of sustainable intensification; others such as building institutional capacity and information dissemination are key to support widespread sustainable intensification. Sustainable intensification also links to adaptation through its effects on farm incomes. Any practices that improve farm incomes allow farming households to build up their assets that can be used in times of stress (e.g. an essential element of adaptive capacity) or that can put households on a different development trajectory altogether. As much as CSA can support SI, the reverse is also often required: farmers will not be adopting practices for climate change adaptation that may not yield improved returns on investments in the short term. SI, like CSA, has a focus on diversification (exploiting complementarities between crops, across crop-livestock systems and in terms of risk management), Diversification is a crucial part of building adaptive capacity.

Climate change mitigation

Food systems contribute significantly to global warming and are responsible for 19–29% of global emissions, the bulk of which come directly from agricultural production activities (i.e. N_2O and CH_4) and indirectly from land cover change driven by agriculture (CO_2) [2•].

Given the need to increase production in many developing countries, agriculture's GHG emissions are likely to increase, largely due to continuing expansion in livestock production, fertilizer use and land cover change [4]. However, the SI approach, with its focus on improving efficiency of production, is crucial to the mitigation objective of CSA: achieving lower N_2O and CH_4 emissions per unit of output. SI on existing agricultural land is also a major potential source of mitigation by reducing land cover change, particularly of carbon-rich forest and wetlands [12]. While less intensive, lower yielding production may generate local environmental benefits, this strategy may require that land is cleared elsewhere to compensate for locally lower yields, leading to greater environmental impacts overall. Globally, total crop yields — mostly cereal and oil crops — increased by 135% between 1961 and 2005 while the area of cropland increased by only 27% [13] (though degree of cropland expansion varies significantly amongst regions). However, increased efficiencies due to intensification can increase incentives for expansion [14,15]. Intensification therefore needs to be combined with policies and price incentives to strengthen its impacts on land sparing [16]. Past efforts to protect forests suggest that managing the forest-farm interface depends on a mix of measures: institutions related to land tenure, zoning of land, forest governance and enforcement of forest boundaries are critical [12,17]. Besides good governance, forest protection also requires attractive agricultural livelihood options to prevent farmers from encroaching and degrading the forest [18].

This discussion illustrates that for achieving the mitigation objective of CSA, we need to go far beyond the simple goal of intensifying agriculture. Both the SI and CSA concepts recognise this reality. They pay particular attention to analysing trade-offs of different options, in this case the trade-offs between intensification in one part of the landscape (or globe) (which may increase emissions of and its likely impacts on land sparing or land cover change in other parts of the landscape. SI and CSA could involve either land sparing or land sharing. Trade-off analyses would involve understanding which is more beneficial for which objective and in what context; and exploring policy and market mechanisms that enhance sharing or sparing initiatives [3••].

CSA case studies showing the role of sustainable intensification

Adaptation and mitigation can be generated through various means: enhancing soil quality generates vital regulating services of buffering, filtering and moderating the hydrological cycle; improving soil biodiversity; and regulating the carbon, oxygen and plant nutrient cycles, enhancing resilience to drought and flooding, and carbon sequestration, for example. These are all components of SI. Below we briefly present four examples of CSA.

(1) *Banana-coffee intercropping*. Climate change will particularly affect *Arabica* coffee [19], which is grown at higher altitudes where temperatures are lower. Rising temperatures not only affect crop physiology but also increases pest and disease pressure [20]. Coffee production rapidly spread across the world in the 1950s and many public authorities have since promoted high-input monocropping systems for smallholders. However, research in East Arica reveals that banana intercropping can increase plot revenue by more than 50% [21]. in both unfertilized and fertilized conditions. Coffee is a shade-tolerant understory tree. Bananas not only provide shade but also reduce incidence of coffee leaf rust [22]. Furthermore, banana intercropping can contribute to mitigation through storing an additional 15–30 t of carbon per ha in the soil.

(2) *Livestock systems intensification*. The sustainable intensification of livestock production systems could contribute enormously to both adaptation and mitigation. These systems are highly variable, spatially as well as productivity-wise and efficiency-wise. A global economic modelling study [23•] investigated changes driven by economic incentives resulting from shifts in demand and relative factor prices between now and 2030 and their effects on the relative distribution of large ruminant animals between rangeland and mixed crop-livestock systems within the same agro-ecological zone. Transitions toward more efficient, intensified systems would result in considerable meat and milk productivity gains both per ha and per kg DM of feed — up to 30% depending on the region — and similar increases in household income. Such changes would also decrease emissions by 736 Mt CO_2 equiv y^{-1} (nearly 10% of all agricultural emissions), mainly through the emissions avoided by not converting 162 Mha of natural land. Transitions may be hampered by constraints such as inadequate access to markets and credit, but supporting shifts to more productive systems in appropriate areas has considerable potential for delivering desirable mitigation, adaptation and food availability outcomes. A specific case of how intensification can be achieved is given next.

(3) *Livestock diet intensification through agroforestry*. Ruminant diets that are higher in quality result in reduced methane output per unit of milk and meat as well as in higher meat and milk productivity. One way in which livestock production can be intensified is through feeding the leaves of trees such as *Leucaena leucocephala*, which is widely grown in the tropics. Adding even a small amount of *Leucaena* leaves to dairy cattle can treble milk yield per day, quadruple weight gain per day, thereby increasing farm income considerably, and reduce the amount of methane produced per kg of meat and milk by factors of 2 and 4, respectively [24]. At the same time, the use of agroforestry trees can increase carbon sequestration [25]. Widespread adoption of this option has substantial mitigation potential, because intensified diets would considerably reduce the number of ruminants needed to satisfy future demand for milk and meat.

(4) *Stone bunds and zaï pits in the Sahel*. Constructing stone bunds along contours is an effective way to harvest water and decrease runoff erosion. When combined with other land management techniques such as zaï pits (shallow bowls filled with compost or manure in which crops are planted), yield of millet or sorghum can double as compared with unimproved land and reach more than 1 t per ha [26,27]. Improved land management often leads to increased tree cover and improved soil fertility and ground water levels. This allows farmers to grow vegetables on small plots near wells, thus increasing both their income and diet diversity. The use of stone bunds can thus lead to nutritional benefits, while also allowing farmers to cope with changing weather (adaptation to wetter or drier climates). Soil fertility is often improved as a result of more manure being applied, and increased tree cover contributes further mitigation benefits. Thus this technique is a climate smart form of sustainable intensification.

As such examples show, sustainable intensification is a cornerstone of CSA, as increased resource use efficiency contributes to both adaptation and mitigation via effects on farm incomes and reduced emissions per unit product [28]. While SI is but a small part of the adaptation agenda, CSA elements such as crop and livestock insurance and use of climate information can all facilitate SI uptake. Intensification, without the focus on sustainability, is not necessarily compatible with CSA (e.g. it could drive up GHG emissions in absolute terms and per unit of output) but there are no trade-offs between CSA and SI. Both SI and CSA are key components of a multi-pronged approach to achieving sustainable food and nutritional security, along with other actions such as reducing over-consumption, reducing food waste, enhancing diets, and adhering to acceptable standards of animal welfare [3••].

Conclusions

SI and CSA are closely interlinked concepts. The main difference is the focus in CSA on outcomes related to climate change adaptation and mitigation. SI is crucial to both adaptation and mitigation. All cases of CSA invariably turn out to be cases of SI. A climate justice perspective necessitates action to assist resource-poor farmers who are most affected by climate change but have contributed least to it, so that developing countries can enhance their food security and speed their economic growth. Actions taken to improve food security and help farmers adapt may often have significant mitigation co-benefits, but they may also have higher upfront costs (e.g. extra labour costs). Identifying appropriate ways to incentivize the uptake of climate smart alternatives is a key priority. In many countries agricultural policy is inextricably linked with economic support for rural economies. There are increasing possibilities for low-income countries to orientate production along pathways that are both more sustainable and more productive. Research and development partners have a key role to play in identifying and promoting climate-smart practices that strengthen rural communities, improve smallholder livelihoods and employment, and avoid negative social and cultural impacts such as loss of land tenure and forced migration. In many developing countries the design and operation of agricultural support could be radically improved, and SI and CSA goals need to be developed within this broad policy context.

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