Coalition on Sustainable Productivity Growth for Food Security and Resource Conservation
Background and Proposal

The need
Agriculture faces the daunting challenge of producing more food to meet the nutrition needs of a growing world population[1] while at the same time dealing with climate change and ever-tightening natural resource constraints.[2] This challenge is made even more complex by the fact that unless safe and nutritious food is affordable, and reliably accessible, food insecurity and malnutrition will persist.[3] In addition, unless farmers and farm workers make decent incomes, poverty will grow, and farming will fail.[4]

Increasing agricultural productivity growth is one of the only ways—if not the only way—to solve this multi-objective optimization problem. Agricultural productivity growth, as measured across all inputs, means producing more (or the same amount) with less inputs, including less land, water, labor, capital and all materials used in production. A complete measure of agricultural productivity provides a measure of the efficiency gains in agricultural production, that is, those gains in production that are not attributable to input intensification.

The importance of efficiency gains and productivity growth for meeting agriculture's multiple objectives cannot be overstated. A recent report by the World Resources Institute (2019) concluded that "*Increased efficiency of natural resource use is the single most important step toward meeting both food production and environmental goals*." This general conclusion is well established in the scientific literature. Folbert et al. (2020), for example find that "*The expansion of farmlands to meet the growing food demand of the world's ever-expanding population places a heavy burden on natural ecosystems. This study shows that about half the land currently needed to grow food crops could be spared if attainable crop yields were achieved globally and crops were grown where they are most productive.*" (The Annex provides an annotated bibliography of recent research on agriculture productivity growth and the environment).

The need for agricultural productivity growth to meet food and conservation needs is not a minority view of a subsector of academia or interest groups. Diverse groups have come to the same conclusion. The EAT-Lancet Commission (Willet et al., 2019), for example, found that food systems transformation requires sustainable intensification, including "*at least a 75% reduction of yield gaps on current cropland.*"

Additional research emphasizes the importance of productivity growth for food affordability, farmer incomes, and poverty alleviation. The World Bank Development Report (2007) stressed that "*In the agriculture-based countries, which include most of Sub-Saharan Africa, agriculture and its associated industries are essential to growth and to reducing mass poverty and food insecurity. Using agriculture as the basis for economic growth in the agriculture-based countries requires a productivity revolution in*

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[1] Food demand is expected to increase between 59% to 98% by 2050 (Valin et al. 2014). Likewise, projections of how much agricultural production will need to increase to meet demand in 2050 range from around 60% (FAO, 2012; WRI, 2019) to 100% (Steensland, 2019; GHI, 2013).
[2] IPBES (2019) provides an overview of growing resource constraints.
[3]Food affordability helps determine dietary patterns. In 2020, healthy diets were unaffordable for more than 3 billion people worldwide (FAO, 2020), helping to explain to some extent growing rates of malnutrition.
[4] See for example the World Bank Development Report (2007) on agriculture for development.

smallholder farming." The 2020 State of Food Security and Nutrition in the World (FAO, 2020) advises that "*Addressing low productivity in food production can be an effective way of raising the overall supply of food, including nutritious foods, by reducing food prices and rising incomes, especially for the poorer family farmers and smallholder producers in low-income and lower-middle-income countries, like farmers, pastoralists and fisherfolk*." The UNFSS Scientific Group Paper on Achieving Zero Hunger (Valin et al. 2021) finds that *"improvements in agricultural productivity, in particular total factor productivity (related to all production factors), offers an opportunity to simultaneously lower the pressure on the environment and increase farmer income by decreasing the input requirements*."

Climate change is increasing the urgency of accelerating sustainable productivity growth. Through its impact on drought, floods, pests, weather variability, and even human health, climate change will, and in many cases already is, challenging farmers to produce more with reduced and less reliable natural resource inputs. Innovative approaches to agricultural productivity growth will be critical to adaptation and to limiting the food security impacts of climate change.[5]

Given tightening natural resource constraints, raising the productivity of existing natural resources—rather than bringing new natural resources into production—is the only viable option to meet food security needs of current and future generations. Only through productivity growth can we meet the world's growing nutrition needs without bankrupting farmers, consumers, and nature.

Why a coalition of action?

We must accelerate agricultural productivity growth to meet the complex, multi-objective challenge of transformation to more sustainable food systems. However, we must also recognize that while agricultural productivity growth is a necessary part of the solution, it is not sufficient to ensure all desired outcomes. Productivity growth on its own, for example, does not necessarily result in increased production of more nutritious foods. Nor does it necessarily result in decreases in negative environmental externalities from agricultural production.

Delivering on the multi-objective potential of agricultural productivity growth requires a holistic, systems approach to resource conservation and efficiency. Siloed efforts to increase agricultural productivity often focus on single objectives, such as water-use efficiency or food affordability, and can have unintended consequences on other objectives. A coalition of action focused on *sustainable* productivity growth could help break silos and deliver on agricultural productivity growth's potential to accelerate progress across multiple objectives.

What is the Coalition's goal?

The goal of the Coalition for Sustainable Productivity Growth for Food Security and Resource Conservation (the SPG Coalition) is to accelerate the transition to more sustainable food systems through productivity growth that optimizes agricultural sustainability across social, economic, and environmental dimensions. The SPG Coalition will advance a holistic approach to productivity growth that considers impacts and tradeoffs among multiple objectives.

The SPG Coalition will contribute to advancing six Sustainable Development Goals (SDGs): 1, 2, 8, 13, 15 and 16. It will directly advance SDGs 2.3 and 2.4:

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[5] See, for example findings, of the U. S. Global Change Research Program (2018) in the fourth national climate assessment.

- SDG 2.3: By 2030, double the agricultural productivity and incomes of small-scale food producers, in particular women, indigenous peoples, family farmers, pastoralists and fishers, including through secure and equal access to land, other productive resources and inputs, knowledge, financial services, markets and opportunities for value addition and non-farm employment.

- SDG2.4 By 2030, ensure sustainable food production systems and implement resilient agricultural practices that increase productivity and production, that help maintain ecosystems, that strengthen capacity for adaptation to climate change, extreme weather, drought, flooding and other disasters and that progressively improve land and soil quality.

Who are Coalition members?
All entities involved with advancing sustainable productivity growth can join the Sustainable Productivity Coalition, including countries, farmer and producer groups, agricultural businesses, NGOs, civil society groups, youth groups, UN agencies, academic groups, think tanks and research institutions.

What do commitments look like and who will track them?
Coalition members commit to advancing, individually and in collaboration with other members, sustainable productivity growth through a holistic approach that considers impacts and tradeoffs among multiple objectives, including as appropriate, objectives related to food security, nutrition, food affordability, farmer and farm worker incomes, climate change adaptation and mitigation, and resource conservation. Possible actions include, but are not limited to, the following:

1. *Link productivity growth goals with resource conservation and climate goals* to help ensure that productivity growth delivers on its conservation promise, including by linking with goals on reducing the negative externalities of agricultural production and increasing the positive ones. Examples include industry actions to increase productivity while simultaneously setting goals to reduce pollution or GHG emissions.

2. *Link conservation and climate goals with productivity goals* to help ensure that conservation and climate action does not reduce food production, increase food insecurity, or grow farmer poverty. Examples include capacity building programs designed to close productivity gaps so that farmers and farm communities can afford to reduce or avoid expansion into new lands, including programs supported by USAID.

3. *Advance, implement, and promote Climate Smart Agriculture and Forestry* (CSAF) and its objectives of sustainably increasing agricultural productivity and incomes; adapting and building resilience to climate change; reducing greenhouse gas emissions and storing carbon within agricultural landscapes.[6] Examples include regional climate hubs that develop regionally appropriate approaches and extension services that support the dissemination and adoption of CSAF.

4. *Join or otherwise participate in the Agriculture Innovation Mission for Climate* (AIM for Climate) to help increase and accelerate global investments in agricultural innovation and R&D that sustainably increase agricultural productivity, improve livelihoods, conserve nature and biodiversity, and help communities adapt and build resilience to climate change, all while reducing greenhouse gas emissions and sequestering carbon.

[6] FAO definition of Climate Smart Agriculture

5. *Advance progress in growing the nutritional productivity of agriculture* to improve the availability and affordability of nutritious foods. This could be achieved by improving the nutrition content of crops and animal derived foods (for example through biofortification and quality selection) as well as by increasing the productivity and nutrition of diverse crops and livestock.

6. *Advance progress in conceptualizing and measuring sustainable productivity growth across objectives* in order to drive even more comprehensive productivity growth, including by incorporating additional outcomes, such as nutrition indicators or externality impacts, into the calculations.

Coalition members are responsible for implementing actions, tracking progress, and reporting on achievements and lessons learned. Countries are responsible for reporting on progress meeting the Sustainable Development Goals, including the six goals targeted by the SPG Coalition: SDGs 1, 2, 8, 13, 15 and 16.

References

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FAO. 2012. *World agriculture towards 2030/2050: the 2012 revision*, Nikos Alexandratos and Jelle Bruinsma, ESA Working Paper No. 12-03, June 2012, Food and Agriculture Organization of the United Nations, www.fao.org/economic/esa

Folberth et al. 2020. The global cropland-sparing potential of high-yield farming. *Nature Sustainability*, 3 (4): 281

Global Harvest Initiative. 2013. 2010 and 2013 Gap Reports www.globalharvestinitiative.org

IPBES (2019): Summary for policymakers of the global assessment report on biodiversity and ecosystem services of the Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services. IPBES secretariat, Bonn, Germany. 56 pages. https://doi.org/10.5281/zenodo.3553579

Steensland, A., (2019) *2019 Global Agricultural Productivity Report: Productivity Growth for Sustainable Diets, and More* (Thompson, T., Ed.), Virginia Tech College of Agriculture and Life Sciences.

USGCRP, 2018: Impacts, Risks, and Adaptation in the United States: Fourth National Climate Assessment, Volume II [Reidmiller, D.R., C.W. Avery, D.R. Easterling, K.E. Kunkel, K.L.M. Lewis, T.K. Maycock, and B.C. Stewart (eds.)]. U.S. Global Change Research Program, Washington, DC, USA, 1515 pp. doi: 10.7930/NCA4.2018

Valin, Thomas Hertel, Benjamin Leon Bodirsky, Tomoko Hasegawa, Elke Stehfest. 2021. Achieving Zero Hunger by 2030, A Review of Quantitative Assessments of Synergies and Tradeoffs amongst the UN Sustainable Development Goals, A paper from the Scientific Group of the UN Food Systems Summit 26 May 2021

Willet et al. 2019. Food in the Anthropocene: the EAT–Lancet Commission on healthy diets from sustainable food systems, Lancet 2019; 393: 447–92 http://dx.doi.org/10.1016/

World Bank. 2007. *World Development Report 2008: Agriculture for Development*, The International Bank for Reconstruction and Development / The World Bank

World Resources Institute (Searchinger, Tim, Richard Waite, Craig Hanson, Janet Ranganathan). 2019. Creating a Sustainable Food Future, A Menu of Solutions to Feed Nearly 10 Billion People by 2050, World Resources Report

Annotated bibliography on sustainable productivity growth/intensification and the environment

Balmford, Andrew et al, (2018) The environmental costs and benefits of high-yield farming, Nature Sustainability
How we manage farming and food systems to meet rising demand is pivotal to the future of biodiversity. Extensive field data suggest that impacts on wild populations would be greatly reduced through boosting yields on existing farmland so as to spare remaining natural habitats. High-yield farming raises other concerns because expressed per unit area it can generate high levels of externalities such as greenhouse gas emissions and nutrient losses. However, such metrics underestimate the overall impacts of lower-yield systems. Here we develop a framework that instead compares externality and land costs per unit production. We apply this framework to diverse data sets that describe the externalities of four major farm sectors and reveal that, rather than involving trade-offs, the externality and land costs of alternative production systems can covary positively: per unit production, land-efficient systems often produce lower externalities. For greenhouse gas emissions, these associations become more strongly positive once forgone sequestration is included. Our conclusions are limited: remarkably few studies report externalities alongside yields; many important externalities and farming systems are inadequately measured; and realizing the environmental benefits of high-yield systems typically requires additional measures to limit farmland expansion. Nevertheless, our results suggest that trade-offs among key cost metrics are not as ubiquitous as sometimes perceived.
https://www.nature.com/articles/s41893-018-0138-5

Burney, J.A., S.J. Davis, and D.B. Lobell. (2010) Greenhouse gas mitigation by agricultural intensification. Proceedings of the National Academy of Sciences of the United States of America 107: 12052–12057.
As efforts to mitigate climate change increase, there is a need to identify cost-effective ways to avoid emissions of greenhouse gases (GHGs). Agriculture is rightly recognized as a source of considerable emissions, with concomitant opportunities for mitigation. Although future agricultural productivity is critical, as it will shape emissions from conversion of native landscapes to food and biofuel crops, investment in agricultural research is rarely mentioned as a mitigation strategy. Here we estimate the net effect on GHG emissions of historical agricultural intensification between 1961 and 2005. We find that while emissions from factors such as fertilizer production and application have increased, the net effect of higher yields has avoided emissions of up to 161 gigatons of carbon (GtC) (590 GtCO2e) since 1961. We estimate that each dollar invested in agricultural yields has resulted in 68 fewer kgC (249 kgCO2e) emissions relative to 1961 technology ($14.74/tC, or ∼$4/tCO2e), avoiding 3.6 GtC (13.1 GtCO2e) per year. Our analysis indicates that investment in yield improvements compares favorably with other commonly proposed mitigation strategies. Further yield improvements should therefore be prominent among efforts to reduce future GHG emissions.
https://www.pnas.org/content/pnas/107/26/12052.full.pdf

Christian Folberth, Nikolay Khabarov, Juraj Balkovič, Rastislav Skalský, Piero Visconti, Philippe Ciais, Ivan A. Janssens, Josep Peñuelas, Michael Obersteiner. The global cropland-sparing potential of high-yield farming. *Nature Sustainability*, 2020; 3 (4): 281
The expansion of farmlands to meet the growing food demand of the world's ever- expanding population places a heavy burden on natural ecosystems. This study shows that about half the land currently needed to grow food crops could be spared if attainable crop yields were achieved globally and crops were grown where they are most productive. The study is the first to provide insight into the amount of cropland that would be required to fulfill present crop demands at high land use efficiency

without exacerbating major agricultural impacts globally. The study results indicate that with high nutrient inputs and reallocation of crops on present cropland, only about half the present cropland would be required to produce the same amounts of major crops. The other half could then in principle be used to restore natural habitats or other landscape elements.

Foresight. (2011). The future of food and farming. London: Government Office for Science
Conclusion with respect to protecting biodiversity: A key argument of this Report is that the global food supply will need to increase without the use of substantially more land and with diminishing impact on the environment: sustainable intensification is a necessity. Pursuit of this agenda requires a much better understanding of how different policy options, both within and outside the food system, affect biodiversity and ecosystem services.
https://www.gov.uk/government/publications/future-of-food-and-farming

Garnett, T., M.C. Appleby, A. Balmford, I.J. Bateman, T.G. Benton, P. Bloomer, B. Burlingame, M. Dawkins, et al. (2013) Sustainable intensification in agriculture: Premises and policies. Science 341: 33–34.
Sustainable Intensification (SI) is a new, evolving concept, its meaning and objectives subject to debate and contest. But SI is only part of what is needed to improve food system sustainability and is by no means synonymous with food security. Both sustainability and food security have multiple social and ethical, as well as environmental, dimensions. Achieving a sustainable, health enhancing food system for all will require more than just changes in agricultural production, essential though these are. Equally radical agendas will need to be pursued to reduce resource-intensive consumption and waste and to improve governance, efficiency, and resilience.
https://science.sciencemag.org/content/sci/341/6141/33.full.pdf

Godfray, Charles. (2015) "The debate over sustainable intensification" Food Security (7):199–208
Abstract: Sustainable intensification is a process designed to achieve higher agricultural yields whilst simultaneously reducing the negative impact of farming on the environment. It is an idea that has had much prominence over the last decade, but which has also raised considerable concerns among a number of different stakeholders. In particular, there are worries that it might be used to justify intensification per se and the accelerated adoption of particular forms of high-input and hi-tech agriculture. Here, some of the issues surrounding the concept of sustainable intensification are explored including: how the term itself has become a centre of debate, how it has been appropriated to support different worldviews, and how it might evolve to help the food system respond to the environmental and food security challenges ahead. Conclusion: My view is that sustainable intensification is an important and valuable concept to help achieve the hugely challenging task of providing affordable food for ten billion people without destroying the natural environment and our capacity to produce food in the future. Yet the debate over the last 10 years has revealed complex issues over the framing and application of the idea, issues that were not apparent, or not anticipated, by the groups of largely natural scientists who formulated the idea. I finish with four broad conclusions that I think arise from this debate. First, words matter. "Sustainable" means different things to different people and can be appropriated by different interest groups. "Intensification" is a red rag to many bulls. Is it worth abandoning the label and reframing sustainable intensification using more neutral terminology? I am not sure there is an obvious alternative, and any new term would almost certainly come with its own baggage; and with all its faults, sustainable intensification does highlight the real tension between improving environmental performance and yields simultaneously. Second, responding to food insecurity involves making hard decisions on consumption and governance, as well as food production and productivity. Always placing discussions about sustainable intensification within this broader food

system context will be helpful in allaying concerns that it is a purely 'productionist' agenda. Third, being clear about what sustainable intensification means for production stimuli in different contexts is critical. In low-income countries there are strong arguments for direct stimulation of production. There is suspicion that such arguments might be used to justify production subsidies in high-income countries, a return to the bad old days of production-oriented Farm Bills and Common Agricultural Policies. Stressing that in developed-countries sustainable intensification involves the economically efficient and environmentally sustainable response to price signals may help to allay these concerns.
Finally, arguments about sustainable intensification have become conflated with arguments about economic and social worldviews, GMOs, animal welfare and other topics. This leads to confusion and lack of clarity. Restricting the term sustainable in sustainable intensification to its environmental aspect and making clear that this in no way reduces the importance of acting on other agendas in the food system (nutrition, social structure of the workforce, poverty reduction etc.) seems a sensible way forward. It is also important to have discussions about the tool box available for sustainable intensification, and the best ways to employ it in different contexts.
https://link.springer.com/article/10.1007/s12571-015-0424-2

Godfray, H.C.J., J.R. Beddington, I.R. Crute, L. Haddad, D. Lawrence, J.F. Muir, J. Pretty, S. Robinson, et al. (2010). Food security: The challenge of feeding 9 billion people. Science 327: 812–818.
Continuing population and consumption growth will mean that the global demand for food will increase for at least another 40 years. Growing competition for land, water, and energy, in addition to the overexploitation of fisheries, will affect our ability to produce food, as will the urgent requirement to reduce the impact of the food system on the environment. The effects of climate change are a further threat. But the world can produce more food and can ensure that it is used more efficiently and equitably. A multifaceted and linked global strategy is needed to ensure sustainable and equitable food security, different components of which are explored here.
https://science.sciencemag.org/content/sci/327/5967/812.full.pdf

Godfray, H.C.J., and T. Garnett. (2014). Food security and sustainable intensification. Philosophical Transactions of the Royal Society B 369: 20120273.
Abstract: The coming decades are likely to see increasing pressures on the global food system, both on the demand side from increasing population and per capita consumption, and on the supply side from greater competition for inputs and from climate change. This paper argues that the magnitude of the challenge is such that action is needed throughout the food system, on moderating demand, reducing waste, improving governance and producing more food. It discusses in detail the last component, arguing that more food should be produced using sustainable intensification (SI) strategies, and explores the rationale behind, and meaning of, this term. It also investigates how SI may interact with other food policy agendas, in particular, land use and biodiversity, animal welfare and human nutrition. Conclusion: SI is in many ways a simple logical deduction from a set of premises: (i) it is virtually certain that demand for food will go up dramatically over the coming decades and increased production must be part of the response (but not the only one) to ensure food security; (ii) conversion of new land for agriculture would cause significant harm to the environment; (iii) reducing the environmental impact of food production is essential for future human wellbeing and prosperity; and (iv) the challenges are such that tools from all forms of agriculture should be considered without prejudice. But accepting these premises simply leads to a description of the aspirational nature of SI, not how it is best achieved. Pursuing SI will entail a major programme of research that involves social sciences as much as the natural sciences. Beyond research the implementation of SI will require trust to be built among the many stakeholders in the food system, all of whom will be required to make compromises of different sorts. And while SI needs to be central to the way we produce food in the future it needs to be integrated within a nexus of strategies

aimed at achieving food system sustainability, in the broadest sense of the phrase. Are there alternatives to SI? At one level, the same approach could be adopted but called by a different name, sustainable yield increases, or ecological intensification, for example. This should not be dismissed as mere semantics—words matter in policy-making and in the public acceptance of policy. The originators of SI were focused primarily on increasing crop yields—but as discussed above 'intensification' has very negative associations for many people as applied to farm animals. On the other hand, some policy documents in the USA now avoid the word 'sustainable' because of its negative connotations for some political groups. At a second level, one might accept the idea that food security poses a major challenge but argue that it can be met by changing diets, reducing waste or by a radical reorganizing of the politico-economic landscape. For this perspective, increases in food production are not required. As argued above, this seems to us a hugely risky strategy—the challenges are such that movement is required on multiple policy fronts. Finally, there is the business-as-usual alternative to SI: unsustainable intensification. As demand for food rises, then the economic pressures to produce food will increase, leading to land conversion, and the types of intensification that damage the environment and other food system goals. In the face of a multitude of externalities (costs not captured in the price), market distortions and time lags, it is inconceivable that the market alone will furnish solutions unaided. The consequences of unsustainable intensification will damage the planet and undermine its capacity to support future food production.
https://royalsocietypublishing.org/doi/pdf/10.1098/rstb.2012.0273

Phalan, B., Onial, M., Balmford, A. & Green, R. E. (2011) Reconciling food production and biodiversity conservation: land sharing and land sparing compared. Science 333, 1289–1291.
The question of how to meet rising food demand at the least cost to biodiversity requires the evaluation of two contrasting alternatives: land sharing, which integrates both objectives on the same land; and land sparing, in which high-yield farming is combined with protecting natural habitats from conversion to agriculture. To test these alternatives, we compared crop yields and densities of bird and tree species across gradients of agricultural intensity in southwest Ghana and northern India. More species were negatively affected by agriculture than benefited from it, particularly among species with small global ranges. For both taxa in both countries, land sparing is a more promising strategy for minimizing negative impacts of food production, at both current and anticipated future levels of production.
https://science.sciencemag.org/content/333/6047/1289

Phalan, B. et al. (2016) How can higher-yield farming help to spare nature? Science 351, 450–451.
Expansion of land area used for agriculture is a leading cause of biodiversity loss and greenhouse gas emissions, particularly in the tropics. One potential way to reduce these impacts is to increase food production per unit area (yield) on existing farmland, so as to minimize farmland area and to spare land for habitat conservation or restoration. There is now widespread evidence that such a strategy could benefit a large proportion of wild species, provided that spared land is conserved as natural habitat (***1***). However, the scope for yield growth to spare land by lowering food prices and, hence, incentives for clearance ("passive" land sparing) can be undermined if lower prices stimulate demand and if higher yields raise profits, encouraging agricultural expansion and increasing the opportunity cost of conservation (***2***, ***3***). We offer a first description of four categories of "active" land-sparing mechanisms that could overcome these rebound effects by linking yield increases with habitat protection or restoration (table S1). The effectiveness, limitations, and potential for unintended consequences of these mechanisms have yet to be systematically tested, but in each case, we describe real-world interventions that illustrate how intentional links between yield increases and land sparing might be developed.
https://science.sciencemag.org/content/351/6272/450

Rockström, et al., (2017) Sustainable intensification of agriculture for human prosperity and global sustainability, Ambio, 46:4-17.
There is an ongoing debate on what constitutes sustainable intensification of agriculture (SIA). In this paper, we propose that a paradigm for sustainable intensification can be defined and translated into an operational framework for agricultural development. We argue that this paradigm must now be defined—at all scales—in the context of rapidly rising global environmental changes in the Anthropocene, while focusing on eradicating poverty and hunger and contributing to human wellbeing. The criteria and approach we propose, for a paradigm shift towards sustainable intensification of agriculture, integrates the dual and interdependent goals of using sustainable practices to meet rising human needs while contributing to resilience and sustainability of landscapes, the biosphere, and the Earth system. Both of these, in turn, are required to sustain the future viability of agriculture. This paradigm shift aims at repositioning world agriculture from its current role as the world's single largest driver of global environmental change, to becoming a key contributor of a global transition to a sustainable world within a safe operating space on Earth.

Royal Society. (2009). Reaping the benefits: Science and the sustainable intensification of global agriculture. London: Royal Society
Food security is one of this century's key global challenges. By 2050 the world will require increased crop production in order to feed its predicted 9 billion people. This must be done in the face of changing consumption patterns, the impacts of climate change and the growing scarcity of water and land. Crop production methods will also have to sustain the environment, preserve natural resources and support livelihoods of farmers and rural populations around the world. There is a pressing need for the 'sustainable intensification' of global agriculture in which yields are increased without adverse environmental impact and without the cultivation of more land……. Past debates about the use of new technologies for agriculture have tended to adopt an either/or approach, emphasising the merits of particular agricultural systems or technological approaches and the downsides of others. This has been seen most obviously with respect to genetically modified (GM) crops, the use of pesticides and the arguments for and against organic modes of production. These debates have failed to acknowledge that there is no technological panacea for the global challenge of sustainable and secure global food production. There will always be trade-offs and local complexities. This report considers both new crop varieties and appropriate agroecological crop and soil management practices and adopts an inclusive approach. No techniques or technologies should be ruled out. Global agriculture demands a diversity of approaches, specific to crops, localities, cultures and other circumstances. Such diversity demands that the breadth of relevant scientific enquiry is equally diverse, and that science needs to be combined with social, economic and political perspectives.
https://royalsociety.org/~/media/Royal_Society_Content/policy/publications/2009/4294967719.pdf

Rudel, Thomas, Laura Schneider, Maria Uriarte, et al., (2009). Agricultural intensification and changes in cultivated areas, 1970–2005. Proceedings of the National Academy of Sciences of the United States of America vol. 106, no. 49: 20657-20680.
Does the intensification of agriculture reduce cultivated areas and, in so doing, spare some lands by concentrating production on other lands? Such sparing is important for many reasons, among them the enhanced abilities of released lands to sequester carbon and provide other environmental services. Difficulties measuring the extent of spared land make it impossible to investigate fully the hypothesized causal chain from agricultural intensification to declines in cultivated areas and then to increases in spared land. We analyze the historical circumstances in which rising yields have been accompanied by declines in cultivated areas, thereby leading to land-sparing. We use national-level United Nations Food

and Agricultural Organization data on trends in cropland from 1970–2005, with particular emphasis on the 1990–2005 period, for 10 major crop types. Cropland has increased more slowly than population during this period, but paired increases in yields and declines in cropland occurred infrequently, both globally and nationally. Agricultural intensification was not generally accompanied by decline or stasis in cropland area at a national scale during this time period, except in countries with grain imports and conservation set-aside programs. Future projections of cropland abandonment and ensuing environmental services cannot be assumed without explicit policy intervention.
www.pnas.org_cgi_doi_10.1073_pnas.0812540106

Steensland, A., (2019) 2019 Global Agricultural Productivity Report: Productivity Growth for Sustainable Diets, and More (Thompson, T., Ed.), Virginia Tech College of Agriculture and Life Sciences.
The world must sustainably produce food, feed, fiber, and bioenergy for nearly 10 billion people in 2050. The food price crisis of 2007–2008 brought global attention to the complex web of environmental, economic, and human challenges that urgently need to be addressed if we are to sustainably meet that goal. By accelerating productivity growth, particularly in small-and medium-scale livestock production, we can achieve global nutrition and environmental goals, while still providing consumers with the animal-source foods they need and want. Environmental sustainability initiatives should prioritize regions experiencing rapid population growth, low rates of agricultural productivity, and significant shifts in consumption patterns — the primary drivers of unsustainable agricultural practices, such as converting forests to crop and rangeland. Global agricultural productivity, measured as Total Factor Productivity, is growing at an average annual rate of 1.63 percent, less than the 1.73 percent required to sustainably produce sufficient nutritious food and agricultural products for 10 billion people in 2050. Total Factor Productivity in low-income countries is alarmingly low, growing at 1.00 percent annually, far below the UN SDG target of doubling the productivity of the lowest-income farmers.
https://globalagriculturalproductivity.org/2019-gap-report/

Struik, Paul and Thomas Kuyper (2017). Sustainable intensification in agriculture: the richer shade of green. A review. *Agron. Sustain. Dev*., 37: 39
Agricultural intensification is required to feed the growing and increasingly demanding human population. Intensification is associated with increasing use of resources, applied as efficiently as possible, i.e. with a concurrent increase in both resource use and resource use efficiency. Resource use efficiency has agronomic, environmental, economic, social, trans-generational, and global dimensions. Current industrial agriculture privileges economic resource use efficiency over the other dimensions, claiming that that pathway is necessary to feed the world. Current agronomy and the concept of sustainable intensification are contested. Sustainable intensification needs to include clarity about principles and practices for priority setting, an all-inclusive and explicit cost-benefit analysis, and subsequent weighing of trade-offs, based on scientifically acceptable, shared norms, thus making agriculture “green” again. Here, we review different forms of intensification, different principles and concepts underlying them, as well as the norms and values that are needed to guide the search for effective forms of sustainable and ecological intensification. We also address innovations in research and education required to create the necessary knowledge base. We argue that sustainable intensification should be considered as a process of enquiry and analysis for navigating and sorting out the issues and concerns in agronomy. Sustainable intensification is about societal negotiation, institutional innovation, justice, and adaptive management. We also make a plea for at least two alternative framings of sustainable intensification: one referring to the need for “de-intensification” in high-input systems to become more sustainable and one referring to the need to increase inputs and thereby yields where there are currently large yield (and often also efficiency) gaps. Society needs an agriculture that demonstrates resilience under future change, an agronomy that can cope with the

diversity of trade-offs across different stakeholders, and a sustainability that is perceived as a dynamic process based on agreed values and shared knowledge, insight, and wisdom.
file:///C:/Users/egolan/Documents/Sustainable%20ag%20hows%20and%20metrics/Sustainable%20intensification/Struik-Kuyper2017_Article_SustainableIntensificationInAg.pdf

Struik, P.C., T.W. Kuyper, L. Brussaard, and C. Leeuwis. 2014. Deconstructing and unpacking scientific controversies in intensification and sustainability: Why the tensions in concepts and values? Current Opinion in Environmental Sustainability 8: 80–88.
Assuming 'ceteris paribus' in terms of the viability of the planet during the coming half-century or so, the rising needs of a burgeoning, but also increasingly rich and demanding world population will drastically change agriculture. Crop yields and animal productivity will have to increase substantially, with the risk of further depleting the resource base and degrading the environment, making food production both the culprit and the victim. Future food security therefore depends on development of technologies that increase the efficiency of resource use and prevent externalization of costs. The current trend is towards intensification, especially more output per production unit so as to increase input efficiency. Whether that trend is sustainable is a matter of strong debate among scientists and policy-makers alike. The big question is how to produce more food with much fewer resources. Sustainable intensification (i.e., increasing agricultural output while keeping the ecological footprint as small as possible) for some is an oxymoron, unless real progress can be made in ecological intensification, that is, increasing agricultural output by capitalizing on ecological processes in agro-ecosystems. Definitions of intensification and sustainability vary greatly. The way these concepts are being used in different disciplines causes tensions and hides trade-offs instead of making them explicit. Inter-disciplinarity and boundary-crossing in terminology and concepts are needed. Implicitly, the operationalization of intensification and sustainability implies appreciation of and choices for values, an issue that is often overlooked and sometimes even denied in the natural sciences. The multidimensional nature of intensification needs to be linked to the various notions of sustainability, acknowledging a hierarchy of considerations underlying decision-making on trade-offs, thus allowing political and moral arguments to play a proper role in the strategy towards sustainable intensification. We make a plea to create clarity in assumptions, norms and values in that decision-making process. Acknowledging that win-win situations are rare and that (some) choices have to be made on non-scientific grounds makes the debate more transparent and its outcome more acceptable both to the scientific community and society at large.
https://www.sciencedirect.com/science/article/pii/S1877343514000748

Tilman, David, Christian Balzer, Jason Hill, and Belinda Beforta (2011) Global food demand and the sustainable intensification of agriculture Proceedings of the National Academy of Sciences of the United States of America 108, no 50: 20260-20264
Global food demand is increasing rapidly, as are the environmental impacts of agricultural expansion. Here, we project global demand for crop production in 2050 and evaluate the environmental impacts of alternative ways that this demand might be met. We find that per capita demand for crops, when measured as caloric or protein content of all crops combined, has been a similarly increasing function of per capita real income since 1960. This relationship forecasts a 100–110% increase in global crop demand from 2005 to 2050. Quantitative assessments show that the environmental impacts of meeting this demand depend on how global agriculture expands. If current trends of greater agricultural intensification in richer nations and greater land clearing (extensification) in poorer nations were to continue, ~1 billion ha of land would be cleared globally by 2050, with CO2-C equivalent greenhouse gas emissions reaching ~3 Gt y^{-1} and N use ~250 Mt y^{-1} by then. In contrast, if 2050 crop demand was

met by moderate intensification focused on existing croplands of underyielding nations, adaptation and transfer of high-yielding technologies to these croplands, and global technological improvements, our analyses forecast land clearing of only ∼0.2 billion ha, greenhouse gas emissions of ∼1 Gt y^{-1}, and global N use of ∼225 Mt y^{-1}. Efficient management practices could substantially lower nitrogen use. Attainment of high yields on existing croplands of underyielding nations is of great importance if global crop demand is to be met with minimal environmental impacts.
https://www.pnas.org/content/pnas/108/50/20260.full.pdf

World Resources Institute (Searchinger, Tim, Richard Waite, Craig Hanson, Janet Ranganathan). 2019. Creating a Sustainable Food Future, A Menu of Solutions to Feed Nearly 10 Billion People by 2050, World Resources Report.
"Increased efficiency of natural resource use is the single most important step toward meeting both food production and environmental goals. This means increasing crop yields at higher than historical (linear) rates, and dramatically increasing output of milk and meat per hectare of pasture, per animal—particularly cattle—and per kilogram of fertilizer. If today's levels of production efficiency were to remain constant through 2050, then feeding the planet would entail clearing most of the world's remaining forests, wiping out thousands more species, and releasing enough GHG emissions to exceed the 1.5°C and 2°C warming targets enshrined in the Paris Agreement—even if emissions from all other human activities were entirely eliminated."