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Sustainable Agricultural Intensification and Climate Smart Agricultural Practices for Improved Food and Climate Security

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Abstract

The grand challenge of increasing production and access to nutritious and safe food to meet growing populations under threat to climate change and climate variability requires systems and transdisciplinary approaches towards agri-food systems. Sustainable agricultural intensification (SAI) focuses on increasing agricultural production from existing farmland without any adverse environmental impacts. There are three major components of SAI which include: (i) genetic intensification (e.g., focused on improving yields, resistance to pests and diseases, tolerance to abiotic stresses, increasing nutritional quality of food products, and using precision breeding, genetics, and genomics tools); (ii) ecological intensification (e.g., focused increasing diversification, farming, cropping and agroforestry systems, resource use efficiency, integrated water, nutrient and pest management); and (iii) socio-economic intensification (e.g., focused on markets, value addition, income generation, policy, creating enabling environment, and building social capital). Climate-smart agricultural (CSA) practices emphasize greenhouse gas emissions, water footprint, and focus on both adaptation and mitigation strategies. Few selected SAI and CSA practices include minimum and no-tillage; cover crops; crop diversity and genotypes selection for effective water use and stress tolerance; diversification (crop mixtures and rotations; perennials, agroforestry systems; forage crops; dual purpose crops); and nutrient recycling from livestock. Overall, developing adoption and scaling of these practices will require convergence of biophysical and social sciences, participatory approaches, public and private sector engagement and commitment of resources from all donor agencies for research and development, human and institutional capacity building.

Keywords: sustainable agricultural intensification; climate-smart agriculture; food security; climate resilience; diversification.

Introduction

Today about 820 million people around the world do not have access to food and about 2 billion people suffer from malnutrition (undernutrition, obesity, and micronutrient deficiency). Furthermore, our agri-food production systems are under the threat of climate change and climate variability. At the present trend of greenhouse gas emissions, global surface temperatures will continue to increase rapidly. It is projected that the global population will reach more than 9.5 or 10 billion by 2050. Meeting the demands of the growing population will require increasing food production by 55 to 60%. The increased food production must come from existing farmland as we do not have more land to bring into agriculture, and it is not desirable, as it will cause irreversible loss to our natural resources and biodiversity.

Focusing on productivity will continue to be important for addressing food and nutrition insecurity. The goal of our agri-food systems must be to increase food production using environmentally sustainable, economically viable, and socially acceptable ways. This can be achieved by using sustainable agricultural intensification (SAI) and climate-smart agricultural (CSA) practices. The SAI emphasizes the provisioning of safe, nutritious, and healthy food at all times to all people from existing farmland without damaging our natural resources and ecosystem health. The CSA practices are those which are intentional in minimizing greenhouse gas emissions, water footprint and include both climate adaptation and climate mitigation strategies. The SAI has several components, that can be broadly divided into three. First: genetic intensification that is focused on increasing yields; building tolerance to biotic and abiotic stresses; improving nutrition using both traditional methods and novel genomic and gene editing tools. Second: Agroecological intensification that is focused on diversification; farming systems; integration of legumes and perennials; improved agronomy; resource use efficiency; integrated nutrient, soil, water and pest management strategies. Third: Socio-economic intensification focused on developing new markets; access to markets; policy interventions; understanding barriers of adoption; building social capital; creating enabling environments; and institutional building. The use of innovations in digital and geospatial tools; artificial intelligence; mechanization; nanotechnology; precision agriculture; entrepreneurship; private sector partnership; and engagement of women and youth will be critical. Overall, it covers, interactions of genotype, environment, management and social aspects including human and social aspects.

Status of SAI Practices

Pretty *et al.,* (2018) did a global analysis and measured progress towards sustainable intensification by farms and hectares, using seven sustainable intensification sub-types: conservation agriculture, integrated crop and biodiversity, integrated pest management, pasture and forage, trees, irrigation management and small or patch systems. From 47 sustainable intensification initiatives at scale (each >10,000 farms or hectares), it was estimated that about 163 million farms (29% of all worldwide) are practicing forms of sustainable intensification on 453 million ha of agricultural land (9% of worldwide total). They concluded that that sustainable intensification may be approaching a tipping point where it could be transformative. They also analysed the growth in social groups that focused on sustainable agriculture and land management systems (Pretty *et al.,* 2020) using the same seven sustainable intensification types. It was observed that across 122 initiatives in 55 countries the number of social groups has grown from 0.50 million (in 2000) to 8.54 million (in 2020). The area of land transformed by the 170–255 million group members was 300 million ha, mostly in less-developed countries (98% groups; 94% area). They concluded that together with other movements, these social groups could now support further transitions towards policies and behaviours for global sustainability.

Few Selected Examples of SAI and CSA Practices

These are few specific successful examples of SAI and CSA practices which have multiple advantages and help with both increasing overall system productivity, minimize environmental damage, and greenhouse and water footprint. These practices also help with reducing waste, re-using and recycling, and efficiently using all resources including both above and below ground. They are not in any order of importance or preference but include diverse examples from around the globe.

No-Till Crop Production System: Zero or no-tillage (no-till) crop production systems reduce soil erosion, improve soil health, enhance soil microbial diversity, and improve soil water quantity and quality (e.g., decrease sedimentation and pollution of water streams and lakes) and decrease greenhouse gas emissions. Long-term studies show that no-till produces equal yields and is more sustainable and enhances soil and water quality and a healthy environment. However, improved and better access to mechanization tools for planting under no-tillage are needed. In addition, weed management options including diverse herbicides, crop rotation systems, and integrated weed management practices would be needed. No-till crop production also leaves and provides crop residues that provide continuous soil cover to minimize evaporation water loss and improve soil organic matter and microbial activity.

Cover Crops: Several species of cover crops (e.g., legumes and grasses) can be grown in summer and winter seasons to provide continuous soil cover. Cover crops provide multiple benefits to farming systems. They minimize soil erosion, improve physical and biological properties, and enhance microbial communities and activity. Cover crops also break the cycle of pests and diseases and add organic matter and nutrients to soils. The selection of cover crop species that thrive in the target environment and farming needs critical investigation. The choice must consider the availability of soil water and nutrients and its potential impact on the following crop grown in rotation. Cover crops that have added value for grazing or biomass will have greater potential for adoption.

Crop Diversity and Genotypes for Effective Water Use and Stress Tolerance: Crop species vary in the amount of water required for their productivity and response to irrigation. Having the right crop species (e.g., life cycle, tolerance to drought and other abiotic stresses), and matching crop species with available soil moisture and rainfall pattern is critical for the longer-term sustainability of water resources. Crops with various water requirements and rooting depth and soil profiles can improve resource use efficiency. Drought stress-tolerant crop species (for example sorghum, millets, mung beans, and cowpea) not only lower water needs but also can withstand moderate drought stress. Many droughts tolerant and water use efficient cultivars and/or hybrids are available in different crop species.

Perennial Crop Production Systems: Traditionally perennial crop production systems were an integral part of crop production farming systems. However, new intense farming systems moved away from that model. Perennial crops conserve resources better than annual crops and use fewer external inputs and provide environmental sustainability. Some annual crop species are being developed into perennial plants. There are some successful examples (e.g. rice, sorghum and kernza) that are showing progress. However, longer-term sustainability and economic viability need further investigation. In addition, further research is needed on potential adoption and their suitability inappropriate land use (e.g. particularly in marginal areas vs. intensive production systems).

Agroforestry Systems: Integrating selected trees and woodlands into farming systems offers ecological, nutritional, and economic benefits. These systems do not compete with the crops – but are complementary and provide nutrients, improve soil nutrition, minimize soil erosion, sequester carbon, and provide ecosystem services through wildlife, water, and air quality. In the longer term, these systems enhance environmental and ecosystem services. These systems can also support livestock and benefit crops when used in an intercropping system. Agro-forestry systems also provide greater diversification and address nutritional needs and income to producers. There are many examples of leguminous trees and shrubs from Africa. In addition, the multi-layered systems of the crop with different heights, morphology, and phenology are popular in Asia.

Crop Rotations and Integrated Management of Pests, Diseases, and Weeds*:* Crop rotations play a key role in managing pests, diseases, and weeds. These pressures are less in crop mixture and crop rotations because insects, pests, and weeds are or can be specific to hosts and crop diversity will break their lifecycle. In addition, having trap crops can also concentrate the pest in particular areas and can be controlled more effectively than if pests are spread across. Push-pull technology where a certain plant species pushes the pest away from the main crop and a trap crop pulls pests towards them have enormous potential to manage pests in a particular cropping system. The use of these methods will minimize herbicides and pesticides and enhance environmental sustainability. Further, the use of integrated pest and weed management practices which includes both biologicals and chemicals (diverse chemical and mixtures) must be used to avoid the development of resistance. Such practices can also enhance natural predators that are efficient in managing pests within the limits.

Forages Crops for Enhanced Animal Nutrition: Sustainable farming systems that incorporate crops and livestock systems need to target forage and pasture crop species to enhance nutrition. Inadequate quality of forage or animal feed not only decreases the productivity of livestock but also the quality of its products. Animals grazing on nutritious forages improve the quality of livestock and quality food that is nutritious, healthy, and safe for humans. Furthermore, improved forage production systems will also minimize the water and carbon footprint of meat production. In recent years' dual-purpose crop varieties (e.g., pearl millet, sorghum, cowpea, soybean, groundnut) are available where grain is human consumption and biomass is animal feed. Some of these varieties are biofortified and have a higher nutrient density in grains and biomass to address the nutritional needs of animals and humans.

Diversification of Pastures and Grazing for Nutrient Recycling: Legume pastures particularly improve soils through biological nitrogen fixation from nodules in the roots. In addition, the leaves of legumes also contain nitrogen that can improve soil quality. Both depleted soils and soils with excess nutrients are not beneficial to the ecosystem. Appropriate pasture management is critical for creating nutrient balance and nutrient availability of the different grazing systems (natural grasslands and legumes) and the combination of livestock species. In addition, effective pasture plant species can also enhance the quality of livestock production and subsequent human nutrition and health.

Soil and Nutrient Management Practices that Minimize Nutrient Loss and Pollution: Methods that will optimize the use and increase input use efficiency (particularly water and nutrients) are critical. Implementing nutrient stewardship principles of the 5 Rs which include – the right source of nutrients, applied at the right rate, at right time, at the right place, and using the right methods to enhance efficiency and sustainability. Using these principles will not only allow us to investigate biological sources of nutrients and minimize our reliance on external inputs but also increase efficiency. These options include the integrated use of both inorganic and organic sources (e.g. legumes, annuals and perennials, biomaterial, composts) of nutrients for economic and environmental benefits.

***Integrated and Efficient Water Management Practices*:** Managing and effectively utilizing water is key to increasing water productivity. In-situ water capture (harvesting) methods such as tied ridges, contour ridges, and the use of live mulches must be considered to increase the infiltration of rainwater and decrease water runoff, soil erosion, and nutrient losses. Further using watersheds and slopes to collect rainwater and store it in ponds and using it for irrigating commercial crops is an effective method to improve water productivity. Stormwater and wastewater from industries and households must be utilized for irrigation. For irrigation technologies, using the principles of 5 R: right source – groundwater, surface water, collected water (ponds), or in-situ water harvesting or recycled water; right rate (how much to irrigate) – depending upon the season, crop needs, soil type, and stored soil moisture; right time – when to irrigate during the crop cycle (most sensitive stages such as planting, pre-flowering, flowering, and grain filling); right method – sprinklers, drip irrigation, sub-surface irrigation; and right place – soil depth, slope and depth. Using these methods will not only increase water use efficiency and water productivity.

Nutrient Recycling from Livestock to Crop Production Systems*:* Manure from livestock contains highly valuable nutrients (N and P) that are essential for crop production. Using manure as a source of fertilizer will minimize the dependence of crop production on fossil fuel-intense inorganic fertilizers. In addition to the direct value of manures, the by-products can also be used for certain commercial products including the production of biogas. However, the balance of manure production and nutrient recycling needs for crop production and its integration requires proper management and planning to make it environmentally safe and sustainable.

Conclusions

The SAI and CSA practices provide holistic solutions to challenges of food, nutrition and climate insecurity. Development, adoption and scaling of best management practices will require integration and convergence of biophysical and social sciences, transdisciplinary and participatory approaches, public and private sector engagement, dedicated support and commitment of resources from all donor agencies, and public support for innovation, human and institutional capacity building. In addition, agricultural research and education organizations must restructure, change and adapt to find local solutions to global challenges and develop a dynamic workforce that deals with societal broader issues and can find local solutions to global problems. Finally, researchers and educators must directly and effectively engage with policymakers and citizens to show the value of research and development and return on investments.

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