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Management Option for Support to Agriculture and Food Security under Climate Change: A Review

Shankar Ram* and Vimal Kumar

Department of Soil Science & Agricultural Chemistry, IAS, BHU, Varanasi-221005

*Corresponding Author E-mail: shankarram32@gmail.com

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ABSTRACT

Agriculture and food security are key sectors for intervention under climate change. Climate change effects on agricultural production directly (e.g. soil, water and crops) and indirectly (e.g. farming/cropping system, post harvest losses and land use). Agricultural production is highly vulnerable even to 2°C (low-end) predictions for global mean temperatures in 2100, with major implications for rural poverty and for both rural and urban food security. World agriculture is at a crossroads and has limited resources. It must produce more from less per capita land and water resources and under changing and harsh climate. Conservation agriculture is a part of sustainable agriculture, aiming at optimizing yields and profits but also at protecting land resources and the environment. Ecohydrology, a study of interaction between ecosystem and hydrology, has an important role to play in advancing food security under changing climate by minimizing the risks of agronomic/pedological drought. Specific interactions involving hydrology and agro-ecosystems relevant to food security are the choice of management systems which may minimize losses of water by surface runoff and evaporation and maximize storage of soil-water in the root zone. The goal is to increase ''green water'' by judiciously managing ''blue water'' and recycling ''gray water''. Therefore, the objective of this article is to describe strategies of advancing food security in an era of rising demands, declining and degrading soil/water resources, and warming and uncertain climate.

Key words: *Climate change, agricultural production, Ecohydrology, green water and food security*

INTRODUCTION

Sustainable agriculture support to agriculture and food security under climate change. Recent decades have seen global food production increasing in line with - and sometimes ahead of demand. However, FAO projects that demand for cereals will increase by 70 percent by 2050, and will double in many low-income countries[5]. Increasing demand for food is an outcome both of larger populations and higher per capita consumption among communities with growing incomes, particularly in Asia. Supply side drivers include efficiency gains associated with vertical integration in industrial food supply chains[19].

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To meet higher demand, food production is obviously of major importance. However, poor households' inability to secure food through markets and non-market channels may limit food security even where food is globally abundant[2]. For those who rely on subsistence agriculture, food security is strongly dependent on local food availability; for the majority who exchange cash, other commodities or labour for food, the access component is of critical importance, especially in relation to dietary diversity and nutrition.

The world demand (billion tons) for cereals was 1.2 in 1974, 1.84 in 1997 and is projected to be 2.50 in 2020. The global demand (million tons) for meat was 109 in 1974, 208 in 1997 and is projected to be 327 in 2020[21]. The rate of increase in food demand is expected to be more in developing than developed countries. Yet, these are also the regions characterized by a wide yield gap[26]. Nonetheless, almost all the future increase in populations will occur in the developing countries. For example, the total population of Sub-Saharan Africa (SSA) will increase from 867 million in 2010 to 1.08 billion in 2020, 1.31 billion in 2030, 1.54 billion in 2040, and 1.76 billion in 2050[25]. The population of developing countries is projected to increase from 4.93 billion in 2000 to 7.95 billion (U.N. medium variant) or 10.10 billion (high variant) by 2050[12]. Unfortunately, the projected climate change may also exacerbate the extreme climatic events and aggravate the risks of drought, flooding, pest infestation, and water scarcity to agro-ecosystems already under great stress[3]. Climate change may affect food systems in several ways[10]. Not all effects of climate change may be adverse to agronomic/food production. Certainly, there will also be favourable effects in some regions. After all, it was the climate change 15-20 millennia ago, the so called, ''Long Summer,'' which made settled agriculture possible. Thus, anticipating opportunities and identifying/realizing some favourable scenarios is an important strategy. Challenges to global food security are: (i) population increase from 7 billion in 2011 to 9.2 billion in 2050, (ii) climate change, (iii) soil degradation by erosion, salinization, organic matter and nutrient depletion, and elemental imbalance, (iv) decreased availability of water, (v) land competition for urbanization, brick making, bio-fuel, and non-agricultural uses, and (vi) preferences toward animal-based diet. Global hotspots food insecurity are South Asia and Sub-Saharan Africa. Adopting concepts of eco-hydrology, enhancing green water in the root zone, can create climate-resilient agriculture to advance food security and improve the environment. An effective governance is needed to implement policies which promote restorative land uses and recommended management practices. Furthermore, payments for ecosystem services may be a useful strategy to promote sustainable intensification of agriculture by resources-poor farmers.

KEY TECHNOLOGIES DEVELOPED FOR SUSTAINABLE MANAGEMENT FOR AGRICULTURE AND FOOD SECURITY UNDER CLIMATE CHANGE

1. Organic farming: Federal statute defines organic farming as "A production system that is managed in accordance with the (national organic standards) to respond to site- specific conditions by integrating cultural, biological, and mechanical practices that foster cycling of resources, promote ecological balance, and conserve biodiversity."

1.1. Organic farming sequesters more carbon, slowing climate change:

Scientists have documented that human activity is responsible for unprecedented levels of greenhouse gases in the atmosphere that trap heat and contribute to global climate change. Letourneau *et al*[14] reported emissions of carbon dioxide (CO_2), nitrous oxide (N_2O) and methane (CH_4), the three main greenhouse gases released by humans have increased more than 70 per cent in the last 30 years.65 Scientists are expressing a sense of urgency about the need to mitigate release of greenhouse gases before catastrophic changes occur in the world's environment. Liebman *et al*[15] reported global climate change is already increasing the frequency and intensity of droughts, floods, heat waves, and major storms. Liu *et al*[16] investigated the destabilized climate is affecting crop production and water availability, causing hunger, malnutrition, and social unrest worldwide. Evidence shows that, not only will organic farms fare better under climate change, the practice of organic farming slows the impact of climate change.

Table-1 represents soil carbon (C), nitrous oxide (N_2O) flux, energy use, and emissions per unit of yield data from the long - term cropping systems trial conducted by the Agricultural Research Service of USDA in Beltsville, Maryland. These factors were integrated into a single measurement, the global warming potential. Global warming potential is calculated by adding together all sources of emissions and sequestrations from each system. Of the three systems studied, organic is the only one that had a negative value for global warming potential, indicating that it had a net uptake of greenhouse gases. McSwiney *et al*[17] This is mostly due to the fact that organic farming built more soil organic matter than non-organic farming did even when the organic farmland was routinely tilled.

1.2. Organic farming reduces toxic chemical exposure:

One of the main reasons organic farming is good for human health is because organic growers do not apply toxic synthetic pesticides, fungicides, or herbicides to their crops. In addition, organic farming practices do not contribute to the development of antibiotic-resistant strains of pathogens because antibiotic use is prohibited in organic livestock production.

1.3. Organic farming enhances biological diversity:

Biological diversity is critical for the health of an environment. In agriculture, both above and below-ground diverse biological communities are important in providing genetic diversity for crops and livestock and maintaining well-functioning, productive agro-ecosystems. "Ecosystem services" refers to a multitude of functions that are provided by well- structured ecosystems. These include atmospheric and climate regulation, water purification and cycling, soil formation and nutrient fixation and cycling[8]. Collectively, ecosystem services and the resource base that supports them has been estimated to be worth on average $33 trillion annually. Greene *et al*[9] reported the value of pollination and control of crop insect pests provided by native insects in the U.S. was estimated to be worth at least $10.6 billion per year.

2. Conservation agriculture: Conservation agriculture is an alternative to conventional agriculture and one of the most efficient systems for sustainable agricultural development, stimulating soil biological activity, increasing organic matter and humus content. Conservation agriculture aims to provide and maintain optimal conditions in the root zone (maximum possible depth for crop roots) in order to enable them to grow and function effectively and without hindrance in capturing plant nutrients and water.

2.1. Tillage and Crop Establishment:

The conventional system for establishment of wheat crops includes repeated ploughing (6-8 ploughing), cultivating, planking, and pulverizing of topsoil. This has been substituted with direct drilling of wheat using zero-till seed drills fitted with inverted T-openers to place seed and fertilizers into a narrow slot with only minimal of soil disturbance and without land preparation. Substitution of conventional tillage with zero or minimum tillage for wheat planting in rice–wheat system, especially in the north-western in indo-gangetic plains (IGP), is a development of regional significance and contributes to the global application of resource conservation technologies in to a new ecosystem. Rice crop is conventionally established as a puddle transplanted crop. Joint efforts of the public institutions and the small-scale private entrepreneurs are giving promising results for development of 'double no-till' system where both rice and wheat crops are drilled with minimum cultivation. This required development of new seed drill fitted with either a double disk openers or mechanical dibbler- 'punch planter', shredders spreader (Happy Seeder) or rotocoulter type disk-drills. Experiments have been undertaken with direct-drilling of rice and wheat crops in both flat and raised bed planting systems[23,22]. In the IGP, new resource conserving technologies and development of appropriate machinery is being combined with novel land and water management approaches for greater efficiency and sustainability of the rice–wheat systems. At the same time, these technologies are generating alternative sources of productivity growth through diversification and intensification of production systems. For example many farmers are now practicing intercropping in raised bed system. In this system wheat is planted on the raised beds and mint or sugarcane in the furrows. Inter-cropping systems such as maize+ potato/onion/red-beets or sugarcane + chickpea/Indian-mustard are also becoming popular with farmers in western Uttar Pradesh, India.

2.2. Water Management:

The total annual irrigation water requirement of the rice–wheat system ranges from 1100 to 1600 mm/yr[4]. Work initiated in Pakistan in close collaboration with the private sector, and later supported by RWC, has successfully adapted the technique of laser land levelling for use in the rice–wheat system. Laser assisted precision land levelling facilitates application of less water more uniformly under flood irrigation, reduces leaching losses and improves crop-stand and yields. In rice–wheat system, precision land levelling saves irrigation water in wheat season by up to 25 per cent reduces labour requirements by up to 35 per cent leads to about 2 per cent increase in the area irrigated due to removal and/or reduction in size of bunds made to impound water for rice cultivation; and increases crop yields by up to 20 per cent[6]. Further work is now in progress in all the RWC countries to integrate other land preparation and crop-establishment methods with laser levelling to reduce water use at the field/ farm/basin levels[20].

2.3. Nutrient Management:

In the case of nitrogen, findings from IRRI's research on matching site-specific capacities of the soil to supply nutrients and to the demand of crop(s) in the system have been reflected in the development of a leaf colour chart (LCC) to help farmers select the right dose and time of application for optimum response in rice. Efforts have also been made to extend the LCC technology to wheat crop by synchronising N application with irrigation practices[24,20]. The LCC has been widely distributed to tens of thousands farmers in the consortium countries to assess response. LCC technology has the potential to save about.15–20 per cent of N fertiliser application in rice[1,20]. The work on other nutrients is less advanced at the farm level although a careful examination of long-term experiments undertaken in the consortium countries by the RWC is identifying nutrient mining (such as of K) and imbalances, along with the loss of C in some situations, as contributing factors to reduced yields[13]. These nutrient management strategies are now being adapted to new crop and tillage systems in presence of residues retained on the soil surface.

2.4. Crop Improvement and Management:

The research on the rice–wheat systems is providing useful information to the component commodity programs of the International Agricultural Research Centres (IARCs) and the National Agricultural Research Institutes (NARIs). As a result rice breeders have given greater attention to such traits as early maturity to allow earlier wheat planting to open opportunities for introduction of short-season crops, e.g. pulses, potatoes. More recent commodity research programs in wheat and rice are examining the genotype tillage interactions of cultivars under zero-till, raised-bed and surface seeding situations for their ability to compete with weeds. These developments mare also contributing to a broader debate about the need for modification of selection criterion in the breeding programs to accommodate new crop establishment and management practices. As more farmers use the new conservation agriculture, there will be a need to adapt crop, variety, fertilizer, water and pest management practices to new systems in relation to local needs.

2.5. Use of Crop residues:

Straw retained on the soil surface reduces weed seed germination and growth, moderates soil temperature and reduces loss of water through evaporation. In addition, crop residue is also an important source of fodder for animals in the IGP countries. Despite these potential benefits, however, large quantities of straw (left over after rice and wheat harvesting) are burnt each year by farmers to facilitate land preparation for crop planting. It is estimated that the burning of one ton of straw releases 3 kg particulate matters, 60 kg CO, 1460 kg CO_2, 199 kg ash and 2 kg SO_2. With the development of new drills, which are able to cut through crop residue, for zero-tillage crop planting, burning of straw can be avoided, which amounts to as much as 10 tons per hectare, potentially reducing release of some 13–14 tons of carbon dioxide[11]. Elimination of burning on just 5 million hectares would reduce the huge flux of yearly CO_2 emissions by 43.3 million tons (including 0.8 million ton CO_2 produced upon burning of fossil fuel in tillage). Zero tillage on an average saves about 60 L of fuel per hectare thus reducing emission of CO_2 by 156 kg per hectare per year Adoption of Conservation agriculture which allow alterations in water, tillage and surface residue management practices can have a direct effect on emissions of greenhouse gases (GHGs) and enhance the carbon stocks of the soil. Soil submergence in rice cultivation leads to unique processes that influence ecosystem sustainability and environmental services such as carbon storage, nutrient cycling and water quality. For example the submergence of soils promotes the production of methane by anaerobic decomposition of organic matter. However, worries that such rice systems are a major contributor to global warming were allayed through a wide-scale study in the region[7]. It has been noticed that methane emissions from rice fields range from 16.2 to 45.4 kg/ha during the entire season, whereas nitrous oxide emission under rice and wheat crops amounts to 0.8 and 0.7 kg/ha, respectively[18]. Incorporation of straw increases methane emissions under flooded conditions, but surface management of the straw under aerated conditions and temporary aeration of the soils can mitigate these effects. Thus, adoption of aerobic mulch management with reduced tillage is likely to reduce methane emissions from the system. The water regime can strongly affect the emission of nitrous oxide, another GHG, which increases under submergence, and is negligible under aeration. Any agronomic activity that increased nitrous oxide emission by 1 kg/ha needs to be offset by sequestering 275 kg/ha of carbon, or reducing methane production by 62 kg/ha. Adoption of Conservation agriculture would favour the decrease of this GHG. In order to minimize nitrate pollution of ground water, volatilization losses of fertilizer N in rice/wheat, and address issues of crop residue burning, receding water table and emission of GHG, measures such as introduction of a legume crop (Mung bean) between wheat and rice, deep placement of nitrogenous fertilisers and raised bed planting and laser land levelling have been developed. With further refinement of double disk planters, punch planter and rotodisk- drill it has become easier to plant crops with through retained residues.

Table 1: Global warming potential (GWP) of three cropping systems

	Δ soil C[a, b]	N_2O flux[a, c]	Energy use[a, d]	Total GWP[a]	Green house gas intensity grain[e]
No till	0	303	807	1110	330
Chisel till	1080	406	862	2348	153
Organic	-1953	540	344	-1069	-207

a kg CO_2 ha^{-1} y^{-1} equivalents

b Average carbon change rates over 11 years.

c N_2O data were measured in 2008.

d Energy use is for a typical year using published values and field records.

e kg CO_2 Mg $grain^{-1}$ equivalents

CONCLUSION

Organic Farming for Health and Prosperity has identified several ways that organic farming is good for human health, economic prosperity and the environment. The increase of organic farmers and acreage, through low- or no-cost changes to the current agricultural system outlined below, will support a thriving economy, people and planet.

Conservation agriculture, which encompass practices that enhance resource- or input-use efficiency; provide immediate, identifiable, and demonstrable economic benefits such as reductions in production costs, and savings in water, fuel, and labor requirements; and ensure timely crop establishment and uniform crop stands, resulting in higher crop yields. Indirect benefits of Conservation agriculture include effective control of Phalaris minor weed in wheat by zero-tillage; replacement of residue burning by retention of crop residues in the Rice-Wheat system, resulting in short-term soil carbon sequestration; reduction in methane emission from nonpuddled and nonflooded rice fields; buildup of soil fertility over the long term, leading to sustainability of intensive rice-wheat cultivation; and generation of rural employment by training and empowering local farm machine manufacturers, custom-hire service providers, retailers and traders, and seed producers. While tillage and crop establishment options have been more successful in wheat, the next frontier will be to make similar headway in rice. In addition, integrated crop management (good agronomy) will continue to be a key to improving productivity and production and eventually attaining national food security. What we need now is to develop an effective program for wider dissemination of proven Conservation agriculture and ICMR to deprived farming communities outside project areas to realize their great impact on food security and farmers' livelihood in South Asia. For this to happen, we need to sensitize agricultural policymakers and encourage them to allocate more resources for wider dissemination of successful RCTs in the region. In addition, there are needs to (a) foster new models of public-private partnerships, especially for faster, scalable, and sustainable delivery of improved crop and resource management technologies along with associated knowledge; and (b) create a highly qualified professional workforce for private- and public-sector extension by establishing a Certified Crop Advisor (CCA) program. The changes in the RWSs have the potential to change the balance in global warming gases. Reduced tillage increases carbon accumulation in the soil and reduces fuel based emissions. Soil submergence is the dominant feature of present rice cultivation in the IGP and leads to unique biogeochemical processes that influence methane and nitrogen gas emissions and nutrient availability. Changes in rice culture to a more aerated system could change the balance of these gases for the better.

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