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ADAPTATION AND MITIGATION TO CLIMATE CHANGE: OPTIMIZING ENERGY USE IN AGRICULTURE

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Abstract: Climate change and agriculture have complex linkage as agriculture is one of the most impacted sectors by climate change and at the same time it is a major contributor to greenhouse gases (GHG) emissions. Overall contribution of agriculture in GHG emission is more than 20% where as its contribution for Methane and Nitrous oxide emissions is 50 and 60%, respectively. These GHGs have manifold higher global warming potential than Carbon dioxide. Agriculture is thus not a green sector mainly because of its high demand for energy and water in food production systems. Energy is the ecological currency and this currency is the sole driver of economic wheels. This energy use is of particular significance in agriculture. Solar energy capture maximization in agriculture requires investment of commercial energy in the form of management operations (direct energy investment) and external inputs like fertilizers and other inputs (indirect energy investment). There is a direct correlation between commercial energy use and yield levels of crops – higher commercial energy use results to higher yields in the absence of any other major limiting factor. After the 1950 there has been as much as 100 fold increase in fossil fuel energy use in agriculture for producing fertilizers, pesticides and for irrigation. Of the total energy use fertilizer applications account for about 70% of energy use and because of large amounts of natural gas and coal used in the manufacturing of N fertilizers, they account for up to 50 of total energy use. Low use efficiency of N fertilizers is the major source of energy leakage and environmental degradation including anthropogenic climate change. High energy investment and poor resource use efficiency has contributed to heavy carbon foot print making agriculture one of the major contributor to climate change with more than 20% share in emission of GHGs. With this present scenario, meeting future needs of burgeoning population through sustainable intensification will be a major challenge. A component of energy audit mechanism in food production system is urgently needed to assess the returns on energy investment to identify most energy efficient systems and also areas of energy leakages. Opportunities exist for minimizing environmental damage from agriculture mainly through maximizing resource use efficiencies of energy intensive external inputs and by adopting conservation agriculture. This review looks at the energy usage, its efficiencies and opportunities for optimizing energy use in crop production through agronomic management in order to make it sustainable and well adapted to climate changed scenario in future.
Keywords: Energy use, Resource use efficiency, Climate change.

Introduction

Agriculture is essentially a solar energy capturing and conversion process to sustain life on Earth. Plants have this unique machinery and mechanism to capture the solar energy and

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convert it to chemical energy by using two other natural substrates carbon dioxide and water. This chemical energy is stored as organic compounds producing a large variety of edible/usable end products to satisfy all basic human needs of food, fiber, fodder and fuel (energy). Ecologically, it is a self-driven production process and if allowed to operate in its natural potential it has no external energy input requirements and thus has zero commercial energy foot print as it only uses abundantly available natural resources. However, in modern intensive agriculture this energy capturing process has been enhanced by superior plant types but mainly driven by heavy commercial energy investments through external inputs like nutrients (fertilizer) and water. Thus, alleviating the limiting factors and maximizing the resource capture and conversion efficiency (Pelletier *et al.,* 2011). Crop productivity is a function of resource supply *X* resource capture *X* resource use efficiency (Monteith,1977). The most critical resources influencing agricultural productivity are radiation, water and nutrients. Thus the yield potential of a genotype (which is defined as 'as the yield of a cultivar when grown in environments to which it is adapted, with nutrients and water non-limiting and with pests, diseases, weeds, lodging, and other stresses effectively controlled' (Evans and Fischer, 1999) depends on whether resources are at optimal or suboptimal levels. Sub-optimal availability of any of these resources limit the utilization and utilization efficiency of other resources and bringing down the crop productivity. For example, at sub-optimal levels of nutrient and water, Radiation Use Efficiency, (RUE) of all major crops is drastically reduced (Azam Ali and Squire, 2002; see Table 1) thus lowering the crop productivity.

Table. 1 Conversion Efficiency of Solar Radiation in Major Crops Under Optimal and Sub-optimal External Inputs (Azam Ali and Squire, 2002).

Crop	**Conversion Efficiency of Solar Radiation (g MJ^{-1})**	
	Optimal Conditions (With High Levels of Commercial Energy)	**Sub-optimal Conditions** (With low levels of Commercial Energy)
C4 Species		
Maize	2.43	1.30
Sorghum	2.69	1.20
Millet	2.62	0.57
C3 Species		
Wheat	1.50	0.80
Rice	2.05	1.00
Barley	1.20	1.10
Potato	1.84	1.00
Soybean	1.30	0.23
Groundnut	1.47	0.47

For example, in maize and sorghum, lower leaf nitrogen can lower solar energy conversion efficiency (Es –dry matter produced from unit captured solar radiation, g MJ^{-1}) from 2.0 g MJ^{-1} at 1.7 g (N) m^{-2} to 0.5 g MJ^{-1} at 0.6 g (N) m^{-2}(Squire, 1990).

Therefore, for this solar energy capturing machine to operate at its full potential, commercial energy has to be invested in the form of operational commercial energy expenditure (Direct commercial energy as fossil fuels for farm management) and external inputs (Indirect commercial energy in the form of inputs like fertilizer, plant protection chemicals, and machinery manufacture). Because of this, modern agriculture is very energy intensive and with growing intensification, both direct & indirect commercial energy use in agriculture has increased more than 100 fold globally (Pimentel, 2009). An analysis of energy use and yield trends in different countries clearly shows that high commercial energy use increases crop yields but at the other extreme relationship is not linear and there can be yield reductions (Woods *et al;,* 2010). High yields in USA and Europe are obtained with much higher energy use per hectare and energy use in agriculture has been doubling every 32 years (Pimentel, 2009). This transformation of agriculture from clean to carbon intensive economic sector is a relatively recent development and has essentially resulted from urgent need to produce more with genetic and agronomic maneuvering to overcome the inherentbiotic and abiotic limitations of energy capture &conversion. While genetic maneuvering has enhanced the yield potential of crops. However, to realize this potential, agronomic maneuvering increasingly required energy intensive external inputs and operations thus raising the energy expenditure (Pathak, 1985, Pimentel, 2009). There has been substantial yield increase globally since 1960 with an average global rise of 140% and in Asia by 280%, albeit, with a heavy human foot print thus, raising a serious question mark on the sustainability of modern agriculture (Pretty, 2008).

In India success of green revolution which resulted in major yield enhancement, can mainly be attributed to application of N fertilizers and irrigation to the input responsive high yielding varieties. However, green revolution was highly commercial energy dependent and caused increased commercial energy use (Table 2). For example, in Punjab between 1965–1966 to 1979–1980 yields and agricultural production increased at the annual rates of 9.1% and 12.5%, respectively whereas the commercial energy consumption during this period increased by 89.3% annually mainly due to greater use of inputs like diesel oil, electricity, machinery, fertilizers and chemicals (Pathak, 1985). Now, with the changes in consumption pattern there is rise in demand for processed & packaged food, the commercial energy cost is further increasing as the post-harvest processes require two to four times more commercial energy that at farm level (Parikh and Syed, 1988).

Table 2. Energy Use and Energy Productivity of some Major Crops in India (NAAS, 2008).

Crop	Total Energy (MJ/ha)	Energy Productivity (kg/MJ)
Food Grains		
Paddy	13076	0.239
Wheat	14657	0.196
Maize	9956	0.215
Sorghum	4745	0.200
Pulses		
Green Gram	4315	0.118
Black Gram	3870	0.105
Bengal Gram	5464	0.190
Oilseeds		
Mustard	8051	0.119
Soybean	6382	0.171
Cash Crops		
Sugarcane	59192	1.039
Cotton	9972	0.094

In the Indian agriculture, fertilizer use is one of the most energy intensive input used in large quantity. The per hectare nutrient application tremendously increased from less than a kg in 1950 to more than 100 kg by 2000. N fertilizer use in cereal crops which constitute for about 70% of total fertilizer use resulted to major yield gains. Every million tons of N fertilizer resulted in 10 million tons of cereal production (NAAS, 2005). However, imbalanced use of fertilizers together with lower use efficiencies caused major soil health and environmental problems. Current fertilizer application ratio is 8.2:3.2:01 which is far from an ideal ratio of 4:2:1 NPK. N use efficiency has remained abysmally low in the Indian agriculture (Satish Chander, 2016). Fertilizers account for nearly 70% of the commercial energy expenditure in agriculture and because N fertilizers production has very high fossil fuel energy requirement it accounts for nearly 50% of total energy use (Woods *et al.,* 2010). N use efficiency is very low around 30-35%, particularly in rice where it is applied in large quantities. The rest 65-70% which is lost is responsible for environmental pollution and climate change. Thus N fertilizers inefficiency is major cause of low energy productivity in agriculture and also for having high carbon foot print. One of the plausible ways to enhance energy productivity is to improve energy input/output ratio by maximizing yield per unit of used resource. This ratio is much higher in countries where yield levels are high. Improving N use efficiency can be a major step forward in this direction. Using nutrient stewardship approach with 4 Rs of applying nutrients in **R**ight quantity, with **R**ight source at **R**ight time and **R**ight place. Similarly, site specific nutrient management can significantly enhance nutrient use efficiencies (Norton, 2014; Satish Chander, 2016). Major advances in biotechnology offers major scope for improving nutrient efficiencies in agriculture. In the recent past major progress in molecular understanding of nutrient use responsiveness and identification of genes for N and P use (Li *et* al., 2006; Chin *et al.,* 2011) can play a major role in enhancing nutrient use efficiencies. Similarly, recent advances in irrigation techniques and development of water use efficient genotypes will help agronomists to improve energy efficiencies in crop production.

With the increasing rate of energy use and low resource use efficiency in terms of energy, water and nutrient use is a major limitation of modern agriculture which is not sustainable and inflicting major damage to the environment (table 2). Future food demands have to be met with sustainable intensification of agriculture. Sustainable intensification is defined *as a process or system where agricultural yields are increased without adverse environmental impact and without the conversion of additional non-agricultural land* (Pretty and Bharucha, 2014). About 80% of energy used in agriculture is from fossil fuel sources and therefore, agriculture is the single largest contributor to greenhouse-gas emission on the planet if deforestation, rice growing and animal husbandry are also included (Natasha, 2011). Major emissions include nitrous oxide from fertilizer and methane from livestock and rice cultivation, as well as carbon dioxide. Agriculture accounts for about 60% of N_2O and about 50% of CH_4 (Smith *et* al., 2007). In the background of threat of climate change with its serious implications for agriculture, developing effective adaptation and mitigation strategies is the only viable option to alleviate its impact on agriculture (Upadhyay, 2016). Since agriculture heavily relies on non-renewable source for its energy requirements, it is imperative to optimize the energy use by enhancing resource use efficiencies through agronomic practices. It should be mandated to have an energy audit of agro-technologies before deploying and disseminating to the farmers. With doubling of food demand by 2050 for burgeoning population unless agriculture becomes energy efficient it will have a major contribution to climate change emissions.

Conclusion

The intricate linkages between energy use in agriculture, yields, economic returns and environmental impacts are complex and need major attention to make it sustainable. Returns on commercial energy investments are abysmally low in modern agriculture. For a sustainable agriculture development commercial energy efficiency has to increase in order to minimize carbon foot print of agriculture. There is scope for improving the commercial energy use efficiencies by adopting resource use efficient agro-technologies. Agronomic management can bring major reductions in commercial energy use by improving nutrient and water use efficiency, minimum or zero tillage and proper crop rotations. Biotechnology is another important tool in reducing the commercial energy use by developing nutrient and water use efficient genotypes. It is imperative to introduce an energy audit system in agricultural production systems to identify areas of energy leakages and for enhancing commercial use efficiency. Energy efficiency has to become a major consideration along with productivity enhancement as part of climate change adaptation and mitigation strategy. A clean agriculture augurs well with the philosophy of 'Development without destruction'.

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