SUSTAINABLE CROP PRODUCTION: PHYSIOLOGY, BIOCHEMISTRY AND MOLECULAR BIOLOGY

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Summary

Solving the persistent hunger problem is not simply a matter of developing new agricultural technologies and practices. Most poor producers cannot afford expensive technologies. They will have to find new types of solutions based on locally-available and/or cheap technologies combined with making the best of natural and human resources. Intensification, combined with the use of the best available technologies and inputs (best genotypes and best agronomic management practices) to maximize yields while at the same time minimizing or eliminating harm to the environment, can be termed ‘sustainable intensification’. Clearly, over the next 50 years we will need to learn to do just this. Farmers are not all the same. Some are more willing to take risks and adopt new technologies than others, while some are simply better farmers than

others. This has been the case since the birth of agriculture, but debates surrounding 'inequality' have, if anything, become more intense with the increasing popularity of genetically modified (GM) crops. Proponents argue that GM crops represent a major breakthrough in the fight against famine and poverty and their economic and other advantages to farmers explain their popularity. What we now need to do is back up that argument with clear examples where we have transferred these technologies, and allowed for sustainable intensification to be given a chance.

1. Introduction

Since the beginning of agriculture, all societies have had to develop sustainable crop systems. At a minimum, crops needed to provide food for the year and seed for next year and the land had to retain the fertility needed to grow next year's crop. However, despite the recognition that one needs to be able to plant a crop into the foreseeable future, there are a many examples of non-sustainable agricultural systems going back thousands of years. Some of the most important examples of non-sustainable agricultural practices involved irrigation based societies that arose 2,000 to 6,000 years ago in present day Iraq, the valley of the Nile, the Yellow River in China and in Central and South America. Many of the lessons of these cultures are now being recognized for the important historical examples that they provide. Sustainable crop production can be viewed as the need to have agricultural practices that are economically viable, meet human needs for food, while at the same time being environmentally positive and concerned with quality of life. These objectives can be achieved in a number of different ways and it needs to be clear that sustainable agriculture is not linked to any particular technological practice. More specifically, sustainable agriculture is not the exclusive domain of organic farming. Rather, sustainable agriculture adopts productive, competitive and efficient practices, while protecting and improving the environment and the global ecosystem, as well as the socio-economic conditions of local communities in line with human dignity. Sustainable agriculture is often an elaborate system that tries to simulate the conditions found in nature such as multiculture, intercropping, use of farmyard manure and remnants, mulching and application of integrated pest management.

All 191 countries of the United Nations have pledged to meet a number of important development goals by the year 2015. Of these, the first goal, to halve the proportion of people who suffer from hunger and whose income is less than one dollar per day, is most relevant to the plant science community. Since 70% of the extreme poor who suffer from hunger live in rural areas, efforts to enhance agricultural productivity will be a key factor in achieving this goal. This challenge comes at a time when the plant sciences are witnessing dramatic advances in understanding fundamental processes involved in plant development and plant scientists are increasingly able to identify genes that control key processes. In addition, increasing pressure to maintain the food security of a rapidly growing population, particularly in the third world, has resulted in soil degradation, deforestation, water scarcity and contamination, the loss of biodiversity, environmental pollution and increased salinity. At the same time, technological innovations and the development of novel genetic tools have resulted in novel approaches to the concept of sustainable agriculture. However, it has also become obvious that there are significant difficulties in transferring this knowledge to the field.

Even though breeders are beginning to recognize the benefits of molecular markers and genomics in crop improvement, the majority of breeding efforts, with the exception of key crops including corn, soybean, cotton and canola do not utilize these techniques, due to their cost. This situation points to the urgent need to find better ways to translate the new advances in basic plant science into concrete successes in agriculture.

These issues have inspired us to look back at the history of agricultural technologies to determine which ones are more sustainable with a view to providing a discussion of the future focus of researchers, government agencies and the agricultural community. In this review, we have tried to address the following questions. First, what examples do we have of specific physiological or biochemical traits that have been used to improve crops and more specifically, to improve the environmental sustainability of the agricultural production system? Second, what have been the real effects of these advances on agricultural sustainability? Third, how can researchers best make agricultural crop research relevant to the challenge of environmental sustainability? Fourth, how can governments transfer these technologies from the research lab to the field? Finally, how can producers use these technological advances in a viable and sustainable manner to improve their productivity and profitability?

2. What is Sustainable Crop Production?

The World Commission on Environment and Development drew attention to the need for strategies to sustain food security and to conserve natural resources. Agenda 21, the plan of action for implementing sustainable development stated that "Major adjustments are needed in agricultural, environmental and macroeconomic policy, at both national and international levels, in developed as well as developing countries, to create the conditions for sustainable agriculture and rural development". For the purpose of this paper, we intend to limit our discussion of sustainable crop production to agricultural practices that are both economically viable, while at the same time being environmentally positive. In simple terms, if a technology can be shown to either increase the economic benefits flowing to the producer or mitigate any of the negative impacts of a particular agricultural system on the environment, then that technology would be viewed as being more environmentally sustainable. While this also means that there will be situations where one must be able to balance these two effects, clearly the ideal technology would increase the profitability of a crop, while reducing the environmental footprint of the crop and its associated production system.

3. Examples of Agriculturally Sustainable Systems

Third world countries, in particular countries that have a long agricultural history have important lessons to teach us about sustainable agriculture. For some countries, there have been no alternatives to sustainable agriculture to meet the needs of the country for food and fiber. Following U.S. sanctions, Cuba was left with no option other than to adopt sustainable practices and its agriculture is now fully organic. Thailand is another example where sustainable agricultural systems are maintained by combining traditional practices with modern technologies to attain the maximum utilization of resources without undo negative environmental impacts. Up to the late 1980s, traditional agriculture in Thailand caused severe soil exhaustion, deforestation, increased flooding, the loss of top soil, etc. Thailand adopted alternative agriculture replacing its traditional approaches during early 1990s. Thailand is now practicing eco-friendly agricultural systems under a variety of different name such as integrated farming, organic farming, and natural farming, all of which attempt to recognize both traditional market values and non-market values. China is unique for its long history of permanent arable farming, low per capita natural resources and, at the same time, having largely achieved food self-sufficiency. Some of the experiences of Chinese farming may provide clues or alternatives to other poor countries in their effort for optimizing the utilization of natural resources, improving soil fertility and increasing food production. In general, there are a number of lessons to be learned from these different experiences.

(1) Farmer must be aware of and have access to organic manuring to maintain and improve soil fertility and productivity. Lands with low cropping intensity may have green manuring with legume plants once or twice a year. This is often dictated by economic factors, but long term experiments (eg. the Rothamstead Experimental plots in England) have repeatedly demonstrated the importance of conserving and recycling plant nutrients. Therefore, one lesson is to explore all possible avenues for recycling nutrients and improving soil nutrition.

(2) Crop rotation and cropping intensification have to be balanced to ensure maximum sustainable yields. Crop rotation ensures optimal utilization of soil fertility at variable depths and provides important disease, insect and weed breaks. Again, economics will often dictate the type of rotations that can be undertaken; however it is important to have disease breaks in any cropping area.

(3) Integrated approaches to control pest and weed need to be widely practiced. Integrated weed and pest management (IPM) involves applying a combination of different agronomic practices together with manual and mechanical control measures to keep weed and insect infestation below the economic threshold level. This concept puts application of any chemicals at the bottom of the list (only when other practices fail) and does not aim to completely eradicate any weed or insect pest. This approach is suitable for countries where farm sizes are small and labor is cheap. It maintains biodiversity and ensures minimum application of chemicals at the same time. In countries where open water bodies such as streams, ponds, rivers and lakes are used for fish culture, IPM is highly valuable in that it makes other “farming” operations more sustainable.

(4) Irrigation has been used extensively to increase crop yield, in addition to the use of chemical fertilizers and pesticides. However, irrigation needs to be balanced with the effect on soil quality (particularly salinity) and water usage, which is becoming an increasing problem.

(5) GMO technologies have become valuable, primarily in providing herbicide tolerant crops and insect resistant crops. Insect resistance genes have proven to not only increase productivity, but also reduce the usage of chemical insecticides.

In organic farming, farmers attempt to convert all forms of organic wastes into organic fertilizers through animal digestion and/or composting. Recycling of organic wastes through animals and biogas generation utilizes effectively the part of organic carbon that can be converted directly to food and useful energy, which would otherwise quickly be lost in the early phase of decomposition. Crop rotation with legumes helps restore and balance soil nutrient supply. Multiple cropping is effective in boosting crop production from limited arable land. Multiculture crops and intercropping, in contrast to monoculture, which is often practiced in commercial farming, can also provide a cushion against money loss. All of these approaches need to be considered in developing sustainable agricultural systems.

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Biographical Sketches

Allen G. Good received his B.Sc. from Trent University in 1977 an M.Sc. from the University of Windsor and his Ph.D. from the University of Ottawa, the latter in 1986. He completed a post-doctoral fellowship from the Plant Biotechnology Institute (National Research Council, Canada) and has been a faculty member at the University of Alberta since 1989. He formed his own start-up company AgriGenomics in 1998 and has worked extensively with industry in agricultural biotechnology. His interests include plant breeding, plant genetics, plant physiology and agricultural biotechnology. He has worked in a variety of areas including drought tolerance, flooding tolerance and nutrient use efficiency in plants. In addition he has a continuing interest in agricultural systems management, applied ecology and sustainable development.

Ashok K. Shrawat received his undergraduate training from the Meerut University in Meerut, India, M.Sc. from Meerut University and his Ph.D. from the DA University in Indore, India in 1999. He completed a post-doctoral fellowship at DA University and then accepted an Alexander von Humboldt fellowship to continue his studies at the Institute of Plant Molecular Biology at the University of Hamburg. He then moved to Canada to accept a research scientist position at AgriGenomics and subsequently moved to the University of Alberta in 2004 as a senior research associate, working on nitrogen use efficiency in cereal crops. He has published 23 referred research papers and is an inventor on 2 patents. His interests include plant transformation, plant physiology and the molecular genetics of plant nutrition and a continuing interest in sustainable agriculture.

Rowshon A. Begam received her B.Sc. in Agriculture in 1998 from the Bangladesh Agricultural University, Mymensingh, Bangladesh and her M.Sc. in plant molecular biology from the University of Queensland (Brisbane, Australia) in 2003. She has been working as an Agriculture Extension Officer with the Bangladesh government since 2001 and is currently on study leave at the University of Alberta where she is studying for her Ph.D. in plant molecular genetics. In her position as an extension officer, she has been involved in field monitoring, evaluation and implementation of improved sustainable agricultural programs and the communication of these programs to farmers through electronic and print media. In addition, she has been actively involved in strategic planning and policy formulation for the Department of Agriculture Extension, Bangladesh government. Her interests include agricultural biotechnology and plant molecular genetics approaches to ecologically friendly agriculture.