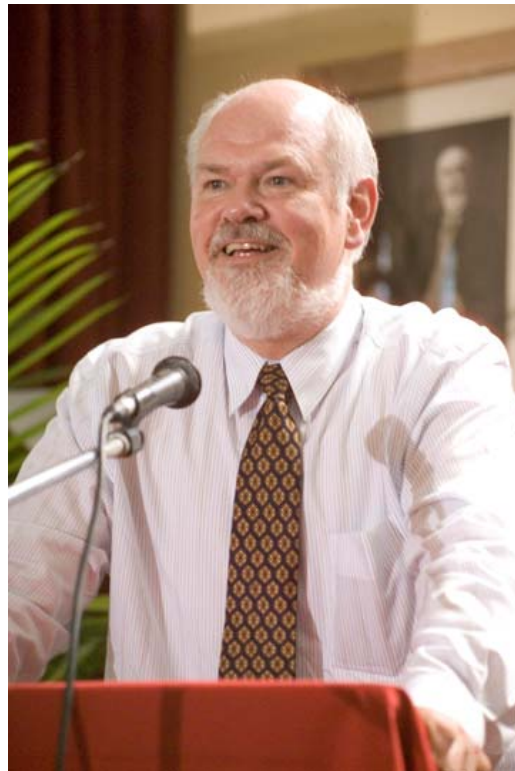


*A draft for comments and feedback*

# ENVISIONING 'POST-MODERN AGRICULTURE'

## A Thematic Research Paper



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## ENVISIONING 'POST-MODERN AGRICULTURE'

As we embark upon this new century, we should consider how advisable it is to continue along our present technological path for agricultural development – simply doing ‘more of the same’ – or whether we should be moving in some other directions. The agricultural techniques and patterns of investment that were developed and practiced in the latter half of the 20<sup>th</sup> century -- widely known as ‘modern agriculture’ -- culminated in what has been called ‘the Green Revolution,’ a subject of both extravagant praise and persistent controversy. How wise is it to extend and even intensify this mode of agricultural development in the coming decades? This is a big question.

While it has been popular in many circles to castigate the Green Revolution, it surely produced many needed benefits. I believe that it has been, on balance, a positive thing even if some persons have been advantaged more than others by it and even though it has had some undesirable and unanticipated side-effects. It was arguably the best avenue for agricultural development that we knew at the time. However, this does not mean that it will be indefinitely the best scientific and practical framework for improving agricultural production.

Even strong defenders of the Green Revolution should be willing to agree that it may not represent the best path for meeting our needs in the 21<sup>st</sup> century. This is an empirical matter, to be assessed as objectively as possible in light of facts and trends. Times and conditions change, and the history of humankind has been one of charting alternative directions in response to new challenges and changing opportunities. Thus, there should be as much burden of proof for perpetuating present Green Revolution technologies as there is on any proposed alternatives.

### Basic Features of ‘Modern Agriculture’

The agriculture which is currently considered as ‘modern’ has four main aspects that can be sketched as follows:

1. **Mechanization:** In the 20<sup>th</sup> century, there was a vast expansion of cultivated area through the use of tractors and other motorized implements. This *land-extensive* strategy of production was both *labor-saving* and *capital-intensive*. It was quite appropriate when a large share of the rural population was becoming urbanized, with ample job opportunities in industry and then services. However, this strategy was also *energy-intensive*, requiring heavy inputs of fossil fuel. Energy was, fortunately, relatively cheap during most of the past century, making ‘modern agriculture’ economically profitable. Mechanization entailed a shift to *mono-cropping*, which was reasonably remunerative for those who could afford the requisite expenses. Unfortunately, such a strategy was more vulnerable to economic and climatic ‘shocks’ than the polycropping that it replaced.
2. **Reliance on Exogenous Inputs:** Along with the mechanization of operations, agriculture was increasingly understood in industrial terms, with reliance on manufactured (more than natural) inputs to produce planned outputs. As agriculture became more dependent on capital investments and on credit, this reorientation toward making production very predictable became essential. Crop plants and animals came to be regarded as equivalent to machines, to be designed and redesigned for maximum efficiency in converting inputs into outputs. Commercial plants and animals, rather than being understood as the living organisms that they are, integral to the environments in which they have co-evolved over millennia, were isolated and insulated as much as possible from their ecological settings. These were regarded as something to be neutralized or modified rather than coopted for better growth processes. *Input-intensive* agriculture became particularly dependent on chemical inputs, both as fertilizers to provide more nutrients and as means for plant and

animal protection. These become more necessary with modern practices because of greater vulnerability of crops and animals and because of financial risks and liabilities.

3. **Genetic Improvement:** Along with mechanization and reliance on external inputs, extensive and successful efforts were made to breed plants and animals that are better suited to mechanical cultivation and more responsive to exogenous inputs. New varieties of crops and new breeds of livestock, poultry, etc. accelerated productivity growth in modern agriculture. Indeed, the Green Revolution is often characterized in terms of the creation and spread of ‘high-yielding varieties,’ even though their success was always dependent in increased inputs of fertilizer, water and agrochemicals. In recent years, improvement has been speeded up by research and interventions at the molecular level. *Genetic modification* using highly sophisticated techniques is heralded as creating new opportunities for agricultural productivity enhancement that are not attainable by conventional breeding methods. Concern with whole organisms and how they function within their environments has been superseded by interest in crop and livestock DNA and in its transformation. *Biotechnology* is now the fastest growing area of agricultural research.
  
4. **Globalization:** These first three elements of modern agriculture can proceed and succeed within national domains; however, in recent decades, raising agricultural productivity further has been driven by an economic philosophy and strategy of *international division of labor*, leading to the expansion of international trade. *Financial incentives* and *market forces* have been shaping research agendas and capital investments in agriculture, which contribute to an expansion in the *scale of production units* and to ever-greater input use and greater capital-intensity. There are now strong financial interests backing ‘modern agriculture,’ which means that most political and bureaucratic thinking is accordingly channeled along these lines.

These reasons and incentives have given to modern agriculture the following characteristics:

- ❑ Land-extensive,
- ❑ Mono-cultural,
- ❑ Labor-saving,
- ❑ Capital-intensive,
- ❑ Energy- and water-consuming,
- ❑ Exogenous input-dependent,
- ❑ Chemically-based,
- ❑ Genetically-focused,
- ❑ Market-oriented,
- ❑ Trade-driven, and
- ❑ Politically favored.

These descriptors are used denotatively, not pejoratively. Do they depict the way that agriculture will or should continue inexorably in the 21<sup>st</sup> century? This is the question addressed here.

### **Limitations on Modern Agriculture**

One of the foundations of modern agriculture – low-cost fossil fuel for meeting its high energy requirements – is already undermined by *rising petroleum prices*. Modern agriculture is much more profitable when the price per barrel of oil is \$25, instead of \$50, \$75, or even \$100. The profitability of modern agriculture is held hostage by its dependence on fossil fuel for energy and also for production of fertilizer and agrochemicals.

There is also the problem, ubiquitous in economics, that whenever certain inputs are used to their maximum, *diminishing returns* are likely to be encountered. This has been happening with input-

dependent agriculture and is becoming a constraint that complements the adverse effects that petrochemical-based inputs and emissions can have on human and environmental health.

In China, for example, the returns to inorganic nitrogen (N) being applied to raise crop yields have dropped off significantly. When the Green Revolution started in China, 1 kg input of N could contribute to 15-20 kg output of additional rice; today that increment is only about 5 kg, and it continues to decline (Peng *et al.*, 2004). Chinese farmers are applying more and more N fertilizer to their crops in an effort to force up yield. However, this is not only uneconomic; it has adverse effects of both water quality and human health. In some parts of China, where application levels for N have reached 450-500 kg/ha, nitrate concentrations in groundwater have reached levels that are 5-6 times above the maximum acceptable to the U.S. Environmental Protection Agency (Hatfield, 2004).<sup>1</sup>

The use of agrochemicals for crop protection has resulted in a kind of ‘chemical treadmill’ where their increased use does not result in an overall reduction in the incidence of pests and diseases. Pimentel (1997) reports that while pesticide use in the United States has gone up 10-fold since World War II, total crop losses in America due to insect damage did not decline but instead went up from 7% to 13%. Thus, chemical inputs have not reduced pest damage in the aggregate and may have added to this.

According to the theory of *trophobiosis* proposed by Chaboussou (2004), supported by extensive research findings reported in the peer-reviewed literature, the use of pesticides and other biocides along with the use of chemical fertilizer has contributed to present-day pest and disease problems. By causing imbalances or deficits in plant nutrition, with associated impacts on plant metabolism, an excess of amino acids and simple sugars is created in plants’ sap and cytoplasm when these are not consolidated efficiently and completely into proteins and polysaccharides. The use of chemical fertilizers and sprays makes plants more attractive and more vulnerable not only to insects, but also to bacteria, fungi and viruses. This vulnerability of crops is exacerbated by the practice of monocropping and by soil compaction from heavy machinery and other stresses that modern agriculture places upon soil systems.

Concern about the use and agrochemicals and mechanization has often been expressed by advocates of organic farming. But this has been usually dismissed by proponents of modern agriculture with the argument that ‘there is no alternative.’ To achieve high levels of food production, it is asserted, modern methods are necessary, even unavoidable. The negative consequences of modern agriculture are justified as ‘the lesser evil.’ However, the following factual considerations create significant reasons for reexamining this unsatisfying rationale.

1. **Some very productive alternatives are becoming available.** These can be grouped under the heading of ‘agroecological’ farming systems. The claim that ‘alternative agriculture’ is unable to meet food requirements (Avery, 1995) can be refuted on empirical grounds (Pretty and Hine, 2001). In particular, the System of Rice Intensification (SRI) discussed below shows that more output can be produced with a *reduction* in inputs and with existing genetic potentials by creating better crop growing conditions.

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<sup>1</sup> Researchers are questioning whether soil and water systems can continue to absorb higher levels of inorganic (i.e., reactive) N without serious ecological damage. Former chief executive of the UK Natural Environmental Research Council, John Lawton, has described the rising use of N fertilizer as “the third major threat to our planet, after biodiversity loss and climate change” (*Nature*, 24 February 2005). He was referring just to the impacts of reactive N on water quality and aquatic ecosystems.

2. **The context of agricultural production is changing substantially and inexorably.** Different relations between and among the factors of production -- along with adverse environmental trends -- are changing the 'playing field' for agriculture. This makes 'the rules of the game' for the 21<sup>st</sup> century different from those that prevailed in the 20<sup>th</sup> century.

Already by the end of the 20<sup>th</sup> century, if one looked at relevant data in time series, it became evident that Green Revolution technologies have lost momentum. Tables 1 and 2 show that 'modern' agricultural production methods and associated outputs are in a kind of transition, with farmers reducing their reliance on chemical inputs. However, this is a complex process. A multiplicity of factors and forces have been emerging and converging to create conditions and pressures for some modification in agricultural technology and organization. From 2001 to 2006, world grain production grew by just 1% per annum, while world grain production per capita has continued to fall (see Table 1), by -1.2% per annum compared to -0.3% per annum in the 1990s.

**Table 1: Percentage changes in agricultural production indicators, by decade, 1961-2001**

Decade	Increase in world grain production, by volume	Increase in world grain production per capita	Increase in fertilizer use, by volume	Increase in pesticide exports, by value
1961 to 1971	48.3%	20.6%	135.5%	93.9%
1971 to 1981	25.3%	4.8%	57.5%	163.7%
1981 to 1991	14.8%	-3.0%	17.4%	34.7%
1991 to 2001	11.1%	-3.1%	2.2%	15.5%

*Source:* Data from the archives of the Worldwatch Institute, Washington, D.C., which compiles data from U.N. Food and Agriculture Organization, U. S. Department of Agriculture, World Bank, and other standard sources. Comparable figures on pesticide use are not available, nor on production, so pesticide exports (for which reliable data are available) are considered here as an indicator of use. Adapted from Buck (2004)

**Table 2: World grain production and fertilizer use (million metric tons) and grain: fertilizer incremental response, 1950-2001**

Year or Averaged Years	Grain production (mmt)	Increase in production vs. prior decade	Fertilizer use (mmt)	Increase in use vs. prior decade
1950	631	--	14	--
1961	805	+174 (28%)	31	+17 (121%)
1969-1971	1116	+311 (39%)	68	+37 (113%)
1979-1981	1442	+326 (29%)	116	+48 (70%)
1989-1991	1732	+290 (20%)	140	+24 (21%)
1999-2001	1885	+153 (9%)	138	-2 (-1.4%)

*Source:* Worldwatch Institute (1994), and data from UN FAO, International Fertilizer Industry Association, and USDA. Adapted from Buck (2004)

### Trends and Forces in the 21<sup>st</sup> Century

In their seminal work on long-term technological change in agriculture, Hayami and Ruttan (1985) highlighted the influence of the changing availability and cost of respective factors of production, in particular, of labor vis-à-vis land. When more land was available relative to labor, as in the U.S.

in the 19<sup>th</sup> and early 20<sup>th</sup> centuries, the technologies devised and used were more land-extensive, with capital substituting for labor. When the relative factor availabilities were reversed, as in Japan, more land-intensive strategies of production were pursued, with more use of labor relative to capital.

Accordingly, we need to consider the overriding influences of resource availability and cost in thinking about future directions for agricultural technological development. There will, of course, be local and national variations according to different circumstances, but the broad outlines of factor availability are as follow. These are matters of objective fact, not of preference or ideology.

- In the 21<sup>st</sup> century, we must expect to have **declining land and water available per capita** with which to meet our global food needs.
  - *World population will continue to increase* through the middle of this century, despite slowing overall rates of population growth. Beyond the next five decades, there may be a reversal and then different incentives and pressures will be at work. We naturally hope there may be no earlier population contraction before then, due to widespread violence, pandemic disease, starvation, or other disasters such as climate change could induce.
  - *Arable land area is diminishing*. Much good agricultural land is being converted each year to permit urban expansion. About 5 million hectares of productive land are being lost each year through erosion, salinization or other results of soil-system degradation, much of it attributable to land management practices of modern agriculture.
  - *Competing demands for water will increase*, while natural supplies become more fluctuating and maybe even reduced in absolute terms, a possibility with climate change. Even if total supply remains constant, we know that as incomes rise, the demand for water for domestic use becomes greater, and also for industrial and other purposes. The agricultural sector will thus have less water to utilize than at present. These trends suggest that the land-extensive strategies of modern agriculture, which have been inefficient in their water use and degrading of water as well as soil quality, will become more and more uneconomic and eventually untenable. Even if land is available, agriculture becomes unsustainable if water is not.
  
- The **costs of energy** have been rising in recent years and are unlikely to return to their previous low levels. Indeed, they are more likely to rise further in the future than to recede.
  - *Large-scale mechanized production* will become more expensive; make labor-intensive methods relatively more profitable as a result.
  - *Fertilizer and agrochemical prices* are also likely to rise, making current input-intensive agriculture less profitable, and for many farmers no longer practicable.
  - *International trade in agricultural commodities* will become less economic because of higher costs of transportation, especially adverse for bulky, low-value commodities. This means 'globalized' solutions to maintaining food security will become less supportable.
  - *Other sources of alternative energy* may become available. But there is as yet not really significant public and private investment in these. So whether other energy sources will actually become sufficient to maintain high-input agriculture is still doubtful.
  - *Subsidization of energy and agricultural inputs* by governments or donor agencies, which 'fueled' the spread of Green Revolution technologies, is an obsolete strategy. There is neither the political will nor the fiscal capacity to return to such policies.

These propositions are hard to dismiss. My argument can be dismissed if we can safely conclude (a) that per-capita arable land and water for agriculture are not going to diminish in the decades ahead, (b) that diminishing returns to agrochemical inputs will be halted, and (c) that energy prices are going to return to 20<sup>th</sup> century levels. However, if these trends are accepted as real and binding, the argument that production systems need to move 'beyond modern agriculture' becomes compelling.

Economic considerations are reinforced by fundamental environmental concerns that need to be taken into account when thinking about the future shape of 21<sup>st</sup> century agriculture.

- **Environmental quality and conservation** are becoming more motivating issues for citizens and for their governments and NGOs. We noted already the growing problems of soil and water pollution by agrochemical applications. Nitrate build-up in groundwater supplies in China is just the most ominous example. Falling water tables in a number of areas where groundwater extraction for agriculture is extensive are going to make large areas unproductive in the future, or even uninhabitable, especially where soil salinization has become extensive. The Punjab Department of Agriculture in India estimates, e.g., that water problems which now affect 30% of the state's agricultural land will affect the whole state by 2023; and the water table which has fallen from 30 to 70 feet over the past 40 years will fall another 90 feet (to 170 feet) over the next 18 years (Singh, 2006). Modern agricultural technologies have not treated the biosphere gently, and there is continuing loss of biodiversity to be reckoned with. While we know do not know much about above-ground losses, we know that we know even less about the all-important losses below-ground.

The use of chemical fertilizers and new varieties may have retarded the shrinking of forest ecosystems in the 20<sup>th</sup> century, as Green Revolution supporters have argued, as gains in grain productivity arguably reduced pressure for conversion of uncultivated areas to cultivation (Borlaug and Dowsell, 2000). But this is not an adequate long-term solution for the conservation of natural ecosystems, since modern technologies have themselves contributed to declining health of soil systems, loss of topsoil, pollution of soil and water resources, and continuing losses of biodiversity. The plea for 'a greener Green Revolution' (Conway, 1999; Swaminathan, 1996) should resonate with everyone who is concerned about the future of the agricultural sector and our planet.

- **Climate change** may well confound many present agricultural technologies. There is no longer much controversy over whether *global warming* is occurring; the debate is now over its probable magnitude and pace. Whether warming is anthropogenic or not, its effects are the same, and they are disastrous for agriculture. This sector is the most vulnerable to changes not only in mean temperature but also to greater *climatic variability*. The term 'extreme events' is a catch-all euphemism for a concatenation of droughts, floods, cold spells, heat waves, etc. that wreak havoc on agriculture (Katz and Brown, 1992; Rosenzweig *et al.*, 2001).

Cropping system adjustments can be made to gradual changes in temperature or even rainfall patterns. But there is no protection for crops, or often for animals, against the effects of 'outlying' temperatures and amounts and timing of rainfall, which are increasingly becoming new norms. Modern agriculture -- with its monoculture and its inattention to plant root development and to soil health -- is more vulnerable to 'extreme events' than earlier-evolved cropping systems that were designed to give crops and animals as well as their growers and their owners some protection against severe fluctuations in climate. Being reminded that 'Mother Nature bats last' should prompt us to look at modern agriculture in a more skeptical manner.

On top of these economic and environmental considerations, we need to take into account that:

- **Millions of rural producers around the world, especially the poorest households, have been bypassed by input-driven modern technologies.** There are many reasons for this: the cost of these technologies, logistical constraints, the need for institutional support and market access that are not available. After four decades, the various barriers to utilizing modern agricultural methods have left the world with still-widespread poverty and food insecurity. If

we are to eliminate these sources of debilitation that diminish the lives of at least one-quarter of humanity:

- The dominant mode of agriculture production in the 21<sup>st</sup> century will have to be much more *accessible to resource-limited farmers* than current modern technologies.
- These technologies will also have to be *much more productive than at present* so that the prices of most basic food supplies are reduced due to productivity advances. This is the only way that urban poverty can be banished without further impoverishing the rural poor. Getting more food production in response to higher prices only makes poverty worse.

I do not believe, as do some critics, that modern agriculture has itself been an important cause of poverty and food insecurity. These conditions pre-existed the agricultural technologies and systems developed over the past half century. Yet although these technologies and systems have been the most productive that the world has ever known and have accomplished some net reduction in poverty and hunger, there are still extensive shortfalls to be made up. Modern agriculture appears poorly positioned to deal with these and to meet the emerging challenges of climate change, which will impose its most devastating effects on the poor and vulnerable.

### Agroecological Alternatives

The integrative supradiscipline of *agroecology* has been formulated over several decades (Altieri, 1987; Carrol *et al.*, 1990; Gliessman, 1997; Uphoff, 2002). Indeed, the origins of such thinking and practice go back much longer (e.g., King, 1911; Howard, 1940). The System of Rice Intensification (SRI) discussed below exemplifies this approach, suggesting ways in which appropriate strategies can deal with the challenges and circumstances of the 21<sup>st</sup> century.

Not all of the methodologies that are consistent with agroecological principles can match the performance of SRI, but they share many features and can be characterized in the following way:

- Agroecological production focuses and manages resources in more intensive, **smaller-scale operations** that are more resource-efficient than extensive, large-scale production units. Many of the economic advantages that larger farms currently enjoy come more from *economies of size* than from true *economies of scale*. This means that their profitability derives more from their market (bargaining) power than from true factor-use efficiency.
- Rather than depend on fossil-fuel energy sources, alternative methods achieve **energy-saving and energy-efficiency** through processes like recycling of biomass, maintaining favorable soil conditions, minimizing losses of energy and other growth factors (e.g., solar radiation, water), diversifying species and genetic resources, and enhancing beneficial biological interactions (Altieri, 2002). Such practices capitalize on *synergies and symbioses* within and among both plants and animals as they function within complex but managed agroecological settings, including reaping the benefits of symbiotic relationships with microorganisms (e.g., Feng *et al.*, 2005; Dazzo and Gianni, 2006).
- Rather than depend so much on *exogenous inputs*, agroecological practices mobilize as much as possible **endogenous biological processes and potentials** that are located within existing plant, animal and microbial genomes and that can be elicited from *interactions* among these diverse organisms and within and between their communities. More attention is paid soil system management (Uphoff *et al.*, 2006), including practices like mulch or cover crops that keep the soil protected and supplied with organic matter.
- Such practices produce plants and animals that are **more resistant to biotic and abiotic stresses**. These are likely to become more severe in this coming century with changes in climate and other conditions. Drought-tolerance and resistance to damage from storms and temperature extremes -- as well as the ability to withstand pest and disease damage -- are all

enhanced by enabling plants to develop larger and healthier root systems through different and better plant, soil, water and nutrient management.

- The **use of organic inputs** to maintain high levels of *soil fertility* is emphasized, following the advice “Don’t feed the plant – feed the soil, and the soil will feed the plant.” Post-modern agriculture is not necessarily ‘organic.’ It favors organic fertilization on pragmatic rather than ideological grounds. If there are nutrient deficiencies in the soil, these can and should be remedied (Chaboussou, 2004). What is rejected is the current *paté de foie gras* approach to raising yields, i.e., the ‘forced-feeding’ plants with large, even excessive amounts of nutrients, not appreciating that plants are biologically programmed to exude ‘excess’ nitrogen (Kronzucker *et al.*, 1999), as excesses are harmful for plant health and performance.
- There is more emphasis on **local production and consumption of food**, cutting the energy costs of long-distance transportation of supplies. This results in improvements in food quality with less nutritional loss. This is not intrinsic to agroecology – its products can be transported and consumed anywhere -- but it is part of the thinking that goes into alternative agriculture.

Taken together, such principles and practices, contribute to an agricultural sector that is:

- *More productive per unit of land and water*, based on intensified agricultural operations, carefully managing all inputs and the plants and animals within these farming systems.
- The practices are, whenever possible, *labor-saving*. Even where more labor-intensive, they give *higher returns to labor*, more output per day or per hour, which is the objective of both those who depend on their own labor for their sustenance and of those who hire labor.
- *Less dependent on fossil-fuel energy and on agrochemical use*, made possible by mobilizing and utilizing existing biological potentials.
- *Environmentally benign*, by making fewer demands on scarce freshwater supplies and by reducing the build-up of harmful chemicals in the soil and water.
- *Resilient to adverse climate effects as well as to pest and disease damage*, by having better root systems and by buffering with polycropping strategies.
- *Able to operate without subsidization*, although the systems produce enough demonstrable positive externalities for people and the environment that some payments could be justified.
- *Accessible to the poor*, with minimal capital costs and few barriers to adoption. Skill and motivation are needed, but not as much investment is necessary as with modern agriculture.

These are the outlines of what can be called ‘post-modern agriculture.’ It may appear to be a ‘wish list,’ but the elements and opportunities are already in place. Of all the resources invested in agricultural research and extension over the past two decades, only the tiniest fraction has been directed in these alternative directions, so much less is known about them than about modern agriculture. Even so, there is a significant scientific base, one sufficient to justify increased experimentation, evaluation and, to the extent that results warrant this, dissemination.

### **The System of Rice Intensification**

SRI is a good example of above principles and results. Much is already known about it, some of which is in published literature (Laulanié, 1993; Stoop *et al.*, 2002; Uphoff 2003; Ceesay *et al.*, 2006; Randiamiharisoa *et al.*, 2006; Satyanarayana *et al.*, 2006; Zhu, 2006; Kabir and Uphoff, 2007; Uphoff, 2007). There have been critiques of SRI (e.g., Doberman, 2004; Sheehy *et al.*, 2004;

McDonald *et al.*, 2006), but these have not been based on any direct or thorough knowledge of SRI, and their conclusions are refutable on empirical and methodological grounds.

In over two dozen countries, ‘the SRI effect’ has now been documented, where more productive phenotypes are produced from any rice genotype by providing a different and more biologically-enriched environment for growth. Yields are increased by 25-100% or more, with a reduction in plant populations (by 80-90%), less water (by 25-50%), without using new ‘improved’ varieties (all varieties respond to the methods, though ‘improved’ varieties give highest SRI yield) and without using chemical fertilizers (just adding compost to the soil), with usually lowered costs of production (by 10-15%), and thus considerably increased net economic returns per hectare.

There is no need to go into detail on SRI methods here. The basic ideas and practices that constitute SRI can be summarized this way:

- ❑ *Transplant young seedlings*, preferably 8-12 days old, certainly less than 15 days old. This preserves their genetic potential for profuse tillering and root growth when the other SRI practices are used as well. Transplanting is not a requirement of SRI, since farmers are now experimenting in a number of countries with crop establishment through *direct seeding*. This is giving good results while saving labor. But so far, the best SRI results have been obtained with the careful transplanting of young plants.
- ❑ *Reduce plant population*, planting sparsely – setting out single seedlings, widely spaced in a square pattern, 25x25 cm -- or wider if the soil is very fertile, instead of many seedlings in clumps that are closer together. Seedlings should be transplanted quickly and gently, so that the root tip does not get inverted upward, with shallow planting, only 1-2 cm deep.
- ❑ *Maintain aerated soil conditions* so that neither plant roots nor soil organisms suffocate from lack of oxygen. This can be done either by applying small amounts of water on a daily basis with some short periods of drying out the soil to the surface-cracking stage (if the soil is not heavy clay); or by alternate flooding and draining paddy fields, wetting and drying the soil intermittently for 3-6 days in each cycle. Previously we advised maintaining a thin layer of water on the field (1-2 cm) after panicle initiation, but we now think that maintaining soil aeration is appropriate throughout the whole growth cycle.
- ❑ *Provide as much organic matter as possible to the soil*. Farmyard manure is good, but any decomposed (composted) biomass – straw, weeds, grass cuttings, tree loppings, etc. – will be beneficial not just for plant nutrition but for better soil structure and supporting abundant and diverse populations of soil biota. Fertilizer can be used with SRI if biomass inputs are not available, but the highest yields have come with organic applications over time.
- ❑ *Actively aerate the soil*. When the field is not flooded, weed growth becomes a greater problem. The best way to control weeds is with a rotary hoe, conoweeder or other implement that aerates the soil while it eliminates weeds. This stimulates the growth of soil organisms that fix or cycle N, solubilize P, improve soil structure and functioning, induce systemic resistance, produce phytohormones, etc. (Randriamiharisoa *et al.*, 2006). Herbicides or manual weeding control weeds but do not enhance the productivity of soil systems.

Along with this, we recommend complementary practices like *seedbed solarization* to produce seedlings as healthy as possible, *seed selection and priming*, and choice of the *most appropriate varieties*. High-yielding varieties and hybrids have given the highest SRI yields (all those over 15 tons/ha), but traditional local varieties can respond very well to SRI practices, with yields in the 6-

10 ton/ha range, and even higher. Since the latter command usually a higher market price, they can be more profitable with SRI than ‘improved’ varieties. The choice is left to farmers.

SRI experience is contributing to an understanding of what ‘post-modern agriculture’ may look like, according to the following observations:

- There is good reason to *re-emphasize biology*, rather than seek productivity gains through chemical inputs and genetic modifications. Biology is different from the disciplines that have shaped and dominated modern agriculture – engineering, chemistry and genetics – in that the association between inputs and outputs is not necessarily proportional and fixed; rather it is quite variable, for good or for bad. In agriculture, a small input such as a seed can produce a huge output; a single rice seed with SRI management can produce > 20,000 seeds. Conversely, large inputs can produce no output at all, if there is mortality. Having a more ‘elastic’ relation between inputs and outputs, and possibly an inverse one, means that instead of always requiring more inputs to achieve more outputs, it is possible to produce more outputs with fewer or reduced inputs, by tapping into the power of biology. That less can give more is not comprehensible with respect to industrial or engineering processes.
- We should *rediscover the potentials of synergy and symbiosis*, which are neglected or dismissed by a worldview that regards ‘free lunches’ as impossible. It is indicative that the growth stunting which results when plants are grown very close together has been labeled as the effect of ‘competition,’ an explanation favored by neo-Darwinian assumptions. But it can be just as well explained by the concept of cooperation, seeing plants as down-regulating their own growth to permit others to survive. Symbiotic relationships between plants and soil organisms began over 400 million years ago, and rather than being separate ‘kingdoms’ (as classified by biologists), they have been co-evolving ever since (Margulis, 1998). A good example of the recent finding, discussed below, that in rice plants, levels of chlorophyll, rates of photosynthesis, and ultimate yield are enhanced simply by the presence of soil microbes (rhizobia) in their leaves.
- We should *give more attention to the biological aspects of soil systems*, going beyond the current agronomic preoccupation with chemical and physical aspects. Soil nutrient pools are regarded essentially as zero-sum, when in fact there can be large amounts of ‘unavailable’ nutrients mobilized through soil microbial activity that changes their status to ‘available’ (Turner *et al.*, 2003; Turner *et al.*, 2006). What first compelled me to take SRI and soil biology seriously was the documentation of 8 ton/ha average yields by farmers using SRI methods around Ranomafana National Park in Madagascar where they had previously averaged only 2 tons/ha – on soils that an agronomy PhD thesis for North Carolina State University (Johnson, 2002) had characterized as extremely poor (in chemical terms): pH 3.8-5.0; low to very low cation exchange capacity (CEC) in all horizons; iron toxicity; aluminum saturation; and available phosphorus levels of 3-4 ppm, less than half the minimum usually considered necessary for acceptable yield. The thesis concluded that only with chemical fertilizer could yield be raised, and yet SRI farmers were able to *quadruple* their average yields, just by managing plants, soil, water and nutrients differently. This experience prompted me to begin taking soil biology seriously and to work with others from various disciplines who could make soil-system potentials comprehensible (Uphoff *et al.*, 2006).
- The benefits of SRI come from and contribute to *human resource development*, so SRI is about more than just increasing production. In disseminating SRI, farmers are regarded as *partners* instead of primarily as *adopters*. SRI concepts and principles are communicated to stimulate thinking and adaptation of SRI practices to local conditions, rather than just instruct farmers on which practices to use and how (Laulanié, 2003). Farmers often become inspired by SRI results and extrapolate the methods to other crops, or devote their own time and energy to

spreading SRI to other farmers, or devise new methods of crop establishment or weed control that make their own efforts more productive and improve neighbor's practices as well. Modern agriculture relied on scientists in their laboratories and on experiment stations to come up with better technologies that were then communicated to farmers through extension personnel, who expected adoption of a package of practices. SRI eschews this *linear model* of agricultural research and development in favor of a *more participatory, reciprocal style*.

### Post-Modern Agriculture

With such experience and learning, we can begin envisioning what could be the shape of an agricultural sector yet to come, building upon but going beyond our current modern agriculture. Since post-modern agriculture does not yet exist, it can only be anticipated and imagined. But some of its outlines can be sketched.

- Post-modern agriculture is *not anti-science* like its counterpart in the arts and humanities. To be successful and to contribute to the well-being of farmers, consumers and the environment (SRI's main 'clients'), it must be fully knowledge-based and thoroughly empirical.
- Post-modern agriculture is not 'backward' as some critics or skeptics like to allege -- as if it is taking agricultural practice back to dibble sticks and superstition. Instead, post-modern agriculture is "the most modern agriculture" because it builds carefully and creatively on advances in scientific knowledge particularly in the disciplines of biology, ecology, and microbiology, and on sub-disciplines like soil microbiology and microbial ecology.

Some examples of the kind of new knowledge that is giving shape and impetus to post-modern agriculture can be cited:

- It has been known for some time that rhizobial bacteria not only inhabit nodules on the roots of leguminous plant species and fix nitrogen there, making N available to the plant for its growth, but also live in, on and around the roots of grass-family (gramineae) species and in free-living association with the roots, providing a number of benefits to plants (Döbereiner, 1987; Doebelaere *et al.*, 2003). Research in Egypt has now shown that rhizobial bacteria live as endophytes in rice plant roots, raising yield and grain protein content while also conferring resistance to biotic and abiotic stress conditions (Dazzo and Yanni, 2006).
- Building upon the work of Dazzo and Yanni, research in China has established that rhizobia living in the root zone (rhizosphere) and infiltrating rice plant roots also migrate up through the roots and stem into and onto the leaves (the phyllosphere). There their presence and activity contribute to higher levels of chlorophyll, higher rates of photosynthesis, and ensuing greater crop yield (Feng *et al.*, 2005). These benefits are not the consequence of any external input, but reflect the long-standing symbiotic relationship between plants and microorganisms.
- Research in the U.S. Department of Agriculture followed up previous findings that tomato plants grown under organic mulch (hairy vetch) and with lower applications of N (100 kg/ha) outproduced by 30-40% - and were healthier than -- similar plants grown with 'modern' practices: mulching with black polyethylene plastic and higher amounts of N (200 kg/ha). Some of the mechanisms contributing to this better performance have now been determined by analyzing the expression of certain well-known genes in the DNA of leaf-tissue cells. Under 'modern' cultivation practices, a certain gene for senescence was found to be switched on, and a gene for producing chitinase (an enzyme that supports crop protection) was found to be switched off; conversely, under more 'organic' conditions, there was converse gene expression (Mattoo and Abdul-Baki, 2006). Plants need to be understood and treated as whole organisms, where what goes on in the roots affects what goes on in the canopy, and vice versa. Similarly,

what goes on in the soil affects what goes on in the plant, and vice versa? This research shows that we should try to understand biological processes *both* at the molecular DNA level and in organisms as a whole, and indeed in the environment, in which they live, grow and die.

We are just beginning to see better through the ‘dark glass’ of soil microbiology and of plant-microbial interactions. The earlier idea that there is nitrogen fixation with leguminous plants, but not with other plant species is incorrect, just as the idea that ruminant animal rely on microbial assistance for their digestion but other animal species do not is wrong. Members of the plant and animal kingdoms are thoroughly suffused with beneficial, indeed often symbiotic microorganisms and could not survive without their services. Humans, we now know, for example, have typically almost 10 times as many microbial cells in their bodies as there are human cells, and they depend on such organisms for synthesis of crucial vitamins and for effective digestion and nutrient absorption (Salminen *et al.*, 2005; other references?).

In the coming decades, as microbiological investigations proceed and expand, we should be able to gain a fuller comprehension of this ‘symbiotic planet,’ as eminent microbiologist and ecologist Lynn Margulis calls it (1998). This book is an excellent introduction for anyone wanting to get a better understanding of this subject area.

Many of the objections made against SRI and other agroecological alternatives have confused science with pragmatics. It is true that there is probably not enough biomass currently available to support a fully ‘organic’ strategy of crop nutrition, and that labor costs presently constitute a barrier to such practices. However, there is accumulating evidence that such nutrition can give superior results, which could make the production and use of biomass quite profitable. A limiting factor is that so few resources have been invested thus far in evaluating plant species, in improving cultural practices, and in devising appropriate implements for growing biomass on non-arable areas in efficient, labor-saving ways. Many practices associated with agroecological practice are currently labor-intensive. But little thought and effort has gone into mechanization or other means to reduce labor requirements.

There are already several studies showing that SRI, initially dismissed by critics as being too labor-intensive for acceptance in ‘modern’ agriculture, is or can become *labor-saving* (e.g., Anthofer, 2004; Sinha and Talati, 2005; Li *et al.*, 2005) We should be clear which limitations on ecologically-based agriculture are intrinsic, and which are matters of practice. The latter can be often be remedied by research and experimentation, as well as by farmer innovation. Only when we have put as much financing and brainpower into improving alternative agriculture as has been invested to create modern agriculture can fair and conclusive evaluations be made.

## Conclusion

Post-modern agriculture is still an emerging body of theory and practice. While some scientific foundations are already in place, farmer practice is probably ahead of scientists’ work at present. This strategy, as a successor to the Green Revolution, is a work in progress that will take another 10-20 years to formulate fully and persuasively. It will not eliminate modern agriculture, but will expand and take root wherever it is found to be more productive, profitable and beneficial.

It has been proposed that the 21<sup>st</sup> century will be ‘the century of biology.’ This claim is often put forward to champion the cause of biotechnology. There are reasons to be hesitant about this proposal, however, because biotechnology as currently pursued is mostly an extension of modern agriculture by other means. It is an application of an engineering mindset that focuses on genetics with continued chemical-input dependence underlying the research efforts, perhaps because this offers the most scope for making and appropriating private benefits and profits.

A particular weakness of current biotechnology is that it continues to focus on organisms or species separately from, and often in competition with, other organisms in their environments. There is no ecological and symbiotic vision of the natural world guiding the research. This could be remedied by adopting a different mindset, but so far, there is little sign of such a viewpoint.

Many critics of the Green Revolution have been dismissive of biotechnology, and particularly of applications that engage in genetic modification. I, for one, find no basis for any across-the-board opposition to genetic modification in agricultural research. One may have objections to corporate control of biotech research processes and results, or consider existing regulatory mechanisms and enforcement inadequate to protect against environmental and other hazards. But that does not mean that the scientific work itself deserves *a priori* condemnation.

Some biotechnology research going on at Cornell University under the direction of Prof. Ray Wu is an example of genetic modification that seems to me well justified and promising, with potentially widespread benefits that will reach the poor (Garg *et al.*, 2002). The work, being done for public rather than for private purposes, would give crop roots greater capacity to produce the sugar trehalose, which confers greater drought-resistance, cold-tolerance and other protection on plants. Trehalose is already produced naturally in the roots, so there are no 'franken-compounds' involved. Such biotechnology work can be very complementary to the agroecological advances that will provide the main foundations for post-modern agriculture (Uphoff, 2007a).

Post-modern agriculture should be thoroughly empirical and explainable in scientific terms, so there should be no antagonism toward science. In return, we should expect scientists to be willing to 'think outside' their disciplinary and other boxes, and to accept information and experience from diverse sources, not being as self-referential as they often are at present, considering other scientists are the most or indeed the only valid sources of knowledge.

In post-modern agriculture, there will also be a much greater role for farmers and non-scientists in the process of innovation and evaluation. Modern agriculture was a fairly tightly-linked and mostly closed system, going from scientific laboratories and experiment stations through an extension system to farmers. There was lip-service given eventually to farmer participation but mostly it was a 'one-way street.' Now a complex 'road network' for agricultural development is emerging, exemplified by SRI as a civil society innovation (Lines and Uphoff, 2005).

That SRI did not emanate from the formal-science system may be one reason for the hostility with which it has been viewed by some rice scientists (SurrIDGE, 2004; Dobermann, 2004; Sheehy *et al.*, 2004). Fortunately, the future will be decided more by productivity than by opinions. It will be shaped by the respective abilities of agricultural practices and systems to meet human needs, understood in terms of their various economic, social, environmental, cultural and other dimensions. From the enumeration of factors and trends reviewed above, a strong case can be made that agroecological approaches are more likely to meet these various needs in the future than can current 'modern' practices in agriculture. It may be too much to expect that the various claims and contentions on both sides will be sorted out according to evidence and results, rather than preconceptions and personal preferences. But efforts should be made. The International Rice Research Institute has recently suggested conducting a multi-year, multi-country comparative assessment of SRI vs. what it will specify as 'best management practices,' according to current mainstream scientific recommendations. This is a good start toward seeking some advancement of scientific consensus and recommended practices.

I hope that protagonists for post-modern agriculture will set some good examples in this regard, so that the debates which will surely ensue can be more productive than acrimonious, generating

considerable light and not just heat. Such a commitment will better serve the interests of farmers and consumers and the environment – for whose collective sake the debate is undertaken.

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