Options for sustainable agriculture in the tropics

An overview

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The adoption of sustainable agricultural practices is viewed as fairly management-intensive.[1] Discussions about sustainable agriculture are apt to be lively, emotional and sometimes controversial. However, technologies appropriately supporting the objectives of sustainability are widely viewed as multi-disciplinary, site-specific, simple and inexpensive. While describing the broadness of disciplines encompassing the sustainability in the context of agriculture, this paper highlights, from various literature, the potential of several initiatives/options available to practitioners of tropical sustainable agriculture.

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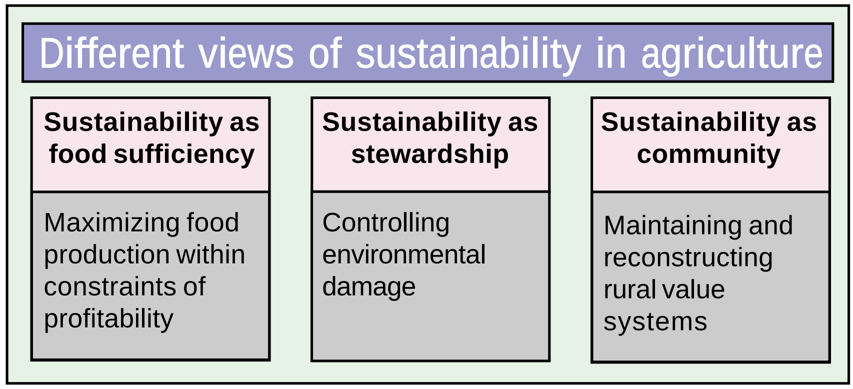
Philosophy of sustainable agriculture

Ecologically, the food system is a recursive loop of production-consumption-recycling. Such a theoretically closed-loop system has its roots in both a particular philosophical approach to life and a systematic way of doing things. It is based on a set of values that reflect a state of awareness and empowerment.

Current problems are mainly due to increased dependency on imported finite resources. Sustainable systems tend to avoid dependence on synthetically compounded fertilizers, pesticides, growth regulators and livestock feed additives. Instead, they rely mainly on crop rotation, crop residues, animal manure, legumes, green manure, off-farm organic waste, mechanical cultivation and mineral-bearing rocks to maintain soil fertility and productivity, and on natural, cultural and biological controls to manage insects, weeds and other pests.[2]

Environmentally sustainable agriculture has characteristics opposite of those of conventional agriculture. It emphasizes growing complementary crops together, in appropriate sequences, keeping the soil covered with mulches and growing crops, including crops and practices that maintain farm productivity, and using the

Figure 1: Describing sustainable agriculture through different angles



detailed knowledge of ecological relationships to minimize the need to purchase inputs such as pesticides and fertilizers to solve problems. For example, in horticultural operations, a pest control strategy may include: [3]

- Use of resistant cultivars;
- Management of soil to maximize biological activity;
- Establishment of conditions to attract natural pest control agents, such as the use of certain flowering plants to attract parasitic and predatory wasps;
- Use of insect traps for monitoring and even controlling pests;
- Management of the ground cover and field borders to promote the predators and parasites of pests;
- Release of specific biological control agents; and
- Use of low-toxic biodegradable/botanical pesticides.

Defining sustainable agriculture

Several definitions have been formulated to describe sustainable agriculture. However, these are often tailored to fit specified circumstances. Some of the definitions are as follows:

- Sustainable agriculture is a way of farming that can be carried out for generations to come. This long-term approach to agriculture combines efficient production with the wise stewardship of the earth's resources.[4]
- A sustainable agriculture is one that, over the long term, enhances environmental quality and the resource base on which agriculture depends; provides for basic human food and fibre needs; is economically viable; and enhances the quality of life for farmers and society as a whole.[5]
- An integrated system of plant and animal production practices having a site-specific application that will, over the long term: satisfy human food and fibre needs; enhance environmental quality and the natural resource base upon which the agriculture economy depends; make the most use of non-renewable resources and on-farm resources, and integrate, where appropriate, natural biological cycles and controls; sustain the economic viability of farm operations; and enhance the quality of life for farmers and ranchers, and society as a whole.[6]
- Agriculture that is socially just, humane, economically viable and environmentally sound.[7]
- A way of producing a stable food supply in perpetuity without degrading the natural resources that support production processes.[8]
- An integrated system of plant and animal production practices, having site-specific application that will, over the long term, satisfy human food and fibre needs, enhance environmental quality and the natural resource base upon which the agricultural economy depends, making the most efficient use of non-renewable resources and on-farm resources, and integrate, where appropriate, natural biological cycles and controls, sustain the economic viability of farm operations and enhance the quality of life for farmers and society as a whole.[9]
- Environmentally friendly methods of farming that allow the production of crops or livestock without damage to the farm as an ecosystem, including effects on soil, water supplies, biodiversity or other surrounding natural resources. The concept of sustainable agriculture is an "inter-generational" one in which we pass on a conserved or improved natural resource base instead of one that has been depleted or polluted. Terms often associated with farms or ranches that are self-sustaining include *low-input*, *organic*, *ecological*, *biodynamic* and *permaculture*.[10]
- A system of agriculture that promotes the well-being of natural and human resources through emphasis on environmental, economic and social factors.[11]
- A system of farming in which each generation inherits the family farm in as good, or better, condition than the last. No soil is eroded, no groundwater is depleted, no weed seeds have accumulated, no pests or diseases flourish, and no toxic chemicals lurk.[12]

In brief, the ideology of sustainable agriculture is popular among practitioners interested in alternative systems of agriculture that can minimize the potential negative effects of intensive agrarian actions needed to feed growing populations. Sustainable agriculture definitions mean different to different people. There are at least three different views (Figure 1)[13]: (a) sustainability as food sufficiency[14]; (b) sustainability as stewardship[15]; and (c) sustainability as community[16]. Obviously, technological tools to support achieving the objectives laid by these views would be different.

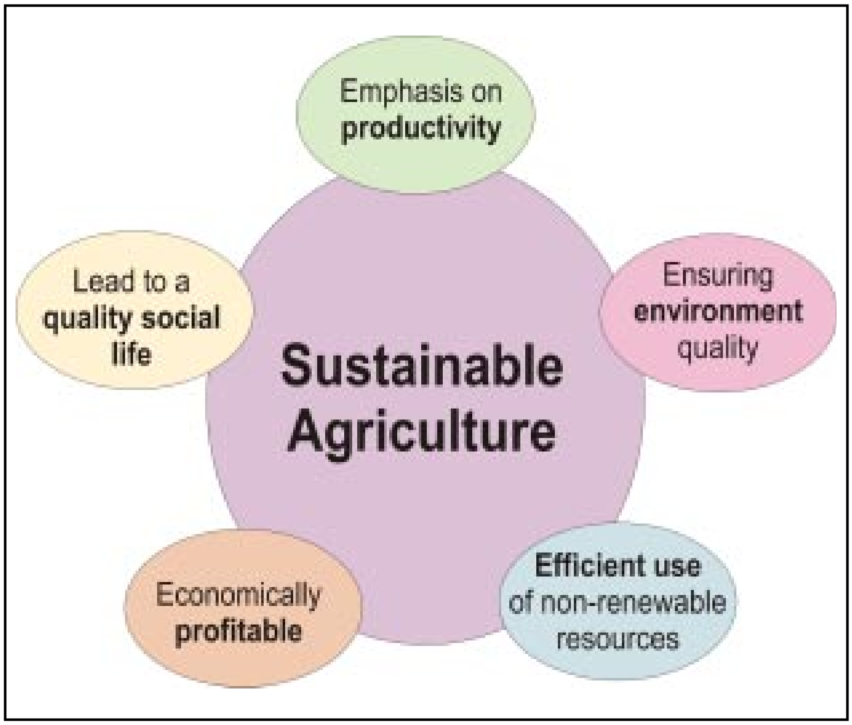
Characteristics of sustainable agriculture

By the definitions of sustainable agriculture, a farm that emphasizes short-run profit but sacrifices environmental quality would not be sustainable in the long run. From the other perspective, pursuing environmental quality without ensuring viability of short-run returns also would be unsustainable. A farm that is highly productive but uses large quantities of non-renewable resources to achieve and maintain that productivity level would also not be considered sustainable in the long run.[17] As the very nature of the agriculture, it should sustainably: [18, 19, 20]

- Meet human needs with a safe, high-quality, and affordable supply of food and fibre;
- Provide access for everyone to nutritious, healthful and affordable food, while ensuring a safe and secure supply of food;
- Produce quality food while preserving open space, abundant wildlife, and other forms of biodiversity;
- Protect the natural resource base and prevent the degradation of air, soil and water quality, while using natural biological cycles and controls;
- Protect environment and promote environmental stewardship, including, conserving and improving soil quality, reducing dependence on non-renewable resources and synthetic fertilizers and pesticides, and minimizing adverse impacts on safety, wildlife, water quality and other environmental resource;
- Offer dignified livelihoods and living wages for all workers in the farm and food sector;
- Build more independent farmers and ranchers producing agricultural products, while ensuring a profitable farm income;
- Assure the economic survival of farming and the well-being of farmers, their families and communities;
- Ensure widespread stable, good living, prosperous farm families and communities; and
- Construct more cohesive communities connected through sustainable agricultural production, and processing and distribution systems based on fair and open markets.

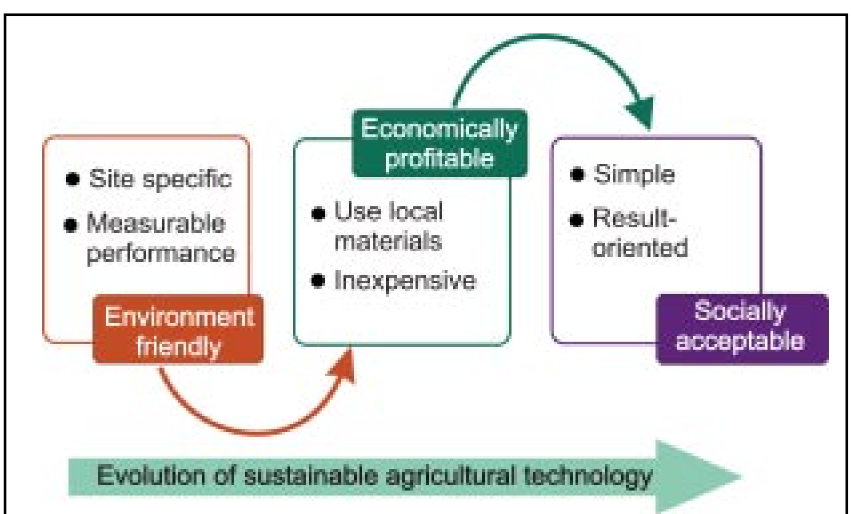
Although ultimately the decision as to whether or not practice sustainable agriculture is made by the farmers and their families, the ease and practicality of doing so are influenced heavily by a number of inter-related factors.[21] Technology, for instance, has a major role to play in the adoption of sustainable agriculture. As expected by the majority of smallholders, technology should be simple, proven as profitable, effective and inexpensive. Figure 2 illustrates five major components of sustainable agriculture – considered as essential for a strong system formation.

Figure 2: Five essential components of Sustainable Agriculture



Similarly, the development process of appropriate technology for sustainable agriculture involves, in general, a certain path of evolution (Figure 3). This process may, however, vary in terms of relative stress on the intermediate steps of evolution to accommodate local constraints. A lab-born technology will achieve the status of 'appropriateness' after it is proved to be environment-friendly – as the first

Figure 3: Development process of appropriate technology for sustainable agriculture



and foremost requirement – and later on satisfy the yardstick of economic profitability for its users; and thereafter acquire social acceptance.

Sustainable agriculture: What is in the name?

With its wide base, sustainable agriculture is coupled with several other terms. Some of these are described briefly below:

Organic or biological agriculture

Organic or biological agriculture refers to a specific set of farming practices that are certified or enforced by the third party. Organic certification indicates that the product is grown using certain specific guidelines, often prepared for attaining as much sustainability as possible. They also ensure minimized use of chemicals and thus lowest possible residues in food products. Popularly adopted guidelines of organic agriculture include: a) crop rotation and soil-building practices; b) cultural, mechanical or biological pest control; and c) use of manure, composts or other such renewable soil amendments.

Low input sustainable agriculture

Low input sustainable agriculture or LISA, as coined by the United States Congress, refers to purchasing fewer off-farm inputs (usually fertilizers and pesticides), and relying more on on-farm inputs (including manure, compost and cover crops). LISA could also be understood as low external input agriculture.

Ecological agriculture

Ecological agriculture refers to a wise blend of organic agriculture with various environmental considerations (for example, on-farm wildlife management). The principles of ecological agriculture advocate harmonic relationship among various stakeholders of agro-ecosystem.

Integrated crop or pest management (ICM/IPM)

ICM/IPM usually has a holistic involvement of inter-related factors, leading to greater impact.

How to achieve sustainability in agriculture?

Agricultural sustainability is not only a difficult concept to define but also difficult to implement and monitor or measure.[22] The World Bank realized that without solving the problems of poverty and population pressure on the land, ensuring ecological sustainability is impossible.[23]

Sustainable agriculture practitioners must meet conservation compliance guidelines but can emphasize some methods of soil conservation over the others. For example, cropping under no-till systems generally does not work well for organic agriculture farmers because of the inability to reduce herbicide use. On the other hand, a tillage rotation system, where no-till system can be alternated with reduced-till and conventional-till practices, is feasible. Another alternative is ridge tillage, which potentially can reduce both tillage and chemical use.

Sustainable agriculture is a dynamic rather than a static concept. What may contribute towards sustainability today may not work as the system evolves, thus requiring a high level of observation and skills that can help adapt to change. Consequently, sustainability is a direction/process and does not by itself result in a final, fixed product.[24]

Sustainable agriculture does not imply going back to old-fashioned or underdeveloped methods of agriculture. Instead, it seeks to combine the wisdom of past practices, including crop rotation of green manure crops. It also blends in careful use of latest technologies, equipment, new pest-resistant crop varieties, and use of information and communication advancements.

The current excessive use of non-renewable resources (because they are relatively cheaper) that will not be available for future generations inhibits the attainment of sustainability. Sustainable agriculture means less emphasis on extractive methods and the use of non-renewable resources, and greater reliance on renewable methods and enhancing the resource base for future generations through exploiting useful biological cycles and thereby saving money on externally purchased inputs.[25]

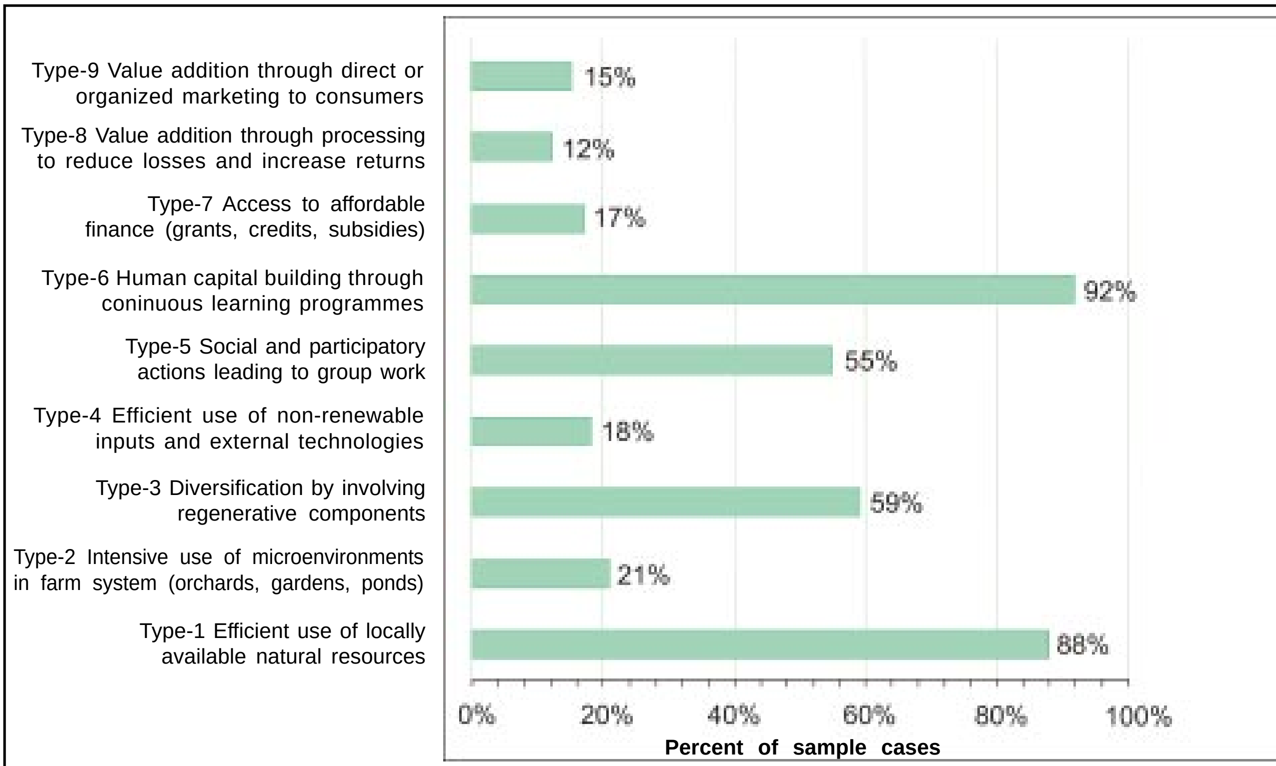
Towards the end of 2000, an audit of sustainable agriculture initiatives was conducted to gauge the worldwide progress towards sustainable agriculture. Information collected on 208 cases from 52 countries comprising nearly 9 million farmers on 29 million hectares was analysed. It was estimated that 3 per cent of the farmed land in Asia, Africa and Latin America used sustainable agricultural technologies. Pretty and Hine (2001)[26] identified nine categories that were employed for yield improvement using sustainable agriculture (Figure 4). They grouped them into three batches. The first batch of improvements involves those that positively affect natural capital in different ways (Types 1-4). The second improves social and human capital (Types 5-6), and the third batch involves improving financial returns to farmers and/or their access to finance and credit (Types 7-9).

Efficient use of locally available natural resources includes water harvesting; soil and water conservation (contour cropping, terraces, minimum tillage, grass strips); composting, livestock manures; irrigation scheduling and management; restoration of degraded or abandoned land; rotational grazing; habitat management for pest-predators; drainage systems and subsoiling; raised beds; bio-pesticides and bio-fungicides.

Intensified use of microenvironment within farm system technologies can significantly increase total food production for rural livelihoods, particularly of protein and vegetables. The options include double-dug beds; vegetables on rice bunds; kitchen gardens; fish ponds; gully cropping and silt traps.

Technologies pertaining to diversification by adding regenerative components result in positive synergistic interactions, where one component of the system positively contributes to the success of other components. The options include legumes in cropping systems (cover crops, green manures) and pastures; integrated livestock (poultry, stall-fed ruminants);

Figure 4: Types of means for sustainable agriculture employed for yield improvement



Source: Pretty and Hine (2001)

fish in rice fields; *Azolla* in rice fields; trees in cropping systems, including woodlots; natural enemy releases for pest control; habitat management for pest control and enhancement of beneficial (hedge rows, beetle banks, flowering and grass strips).

Options for the efficient utilization of non-renewable inputs include new seeds, precision-farming (including patch spraying, targeted inputs, and slow-release for pesticides and fertilizers); low dose of (and non-toxic) sprays; veterinary services; pheromones, sterile males; resistant crop varieties and livestock breeds; machinery (handtools, ploughs); and new cash crops, including energy crops.

Social and participatory activities include farmers' research and experimentation groups; resource management and users' groups (watersheds, fisheries, irrigation, forest protection); credit groups; and horizontal partnerships among external agencies (non-government and government organizations; private and public entities).

A major constraint in the transition towards more sustainable systems is the levels of human knowledge and skills required for the management of more complex systems (it is much easier, for example, to spray a pesticide than it is to farm for beneficial insects). Options for building farmers' knowledge and skills to improve analytical skills and capacities to innovate and control their farm systems include farmers' field schools for improving agro-ecological knowledge; leadership training; adult literacy classes; computer-based knowledge development; farmer-to-farmer extension; and farmer experimentation programmes.

Improving access to finance is a vital way to help farm families develop more sustainable systems of management. The options include access to affordable credit; access to government grants and subsidies; increased returns on sales of produce; and attracting new sources of money for natural capital (eco-tourism, hunting of wildlife; carbon credits for sequestration).

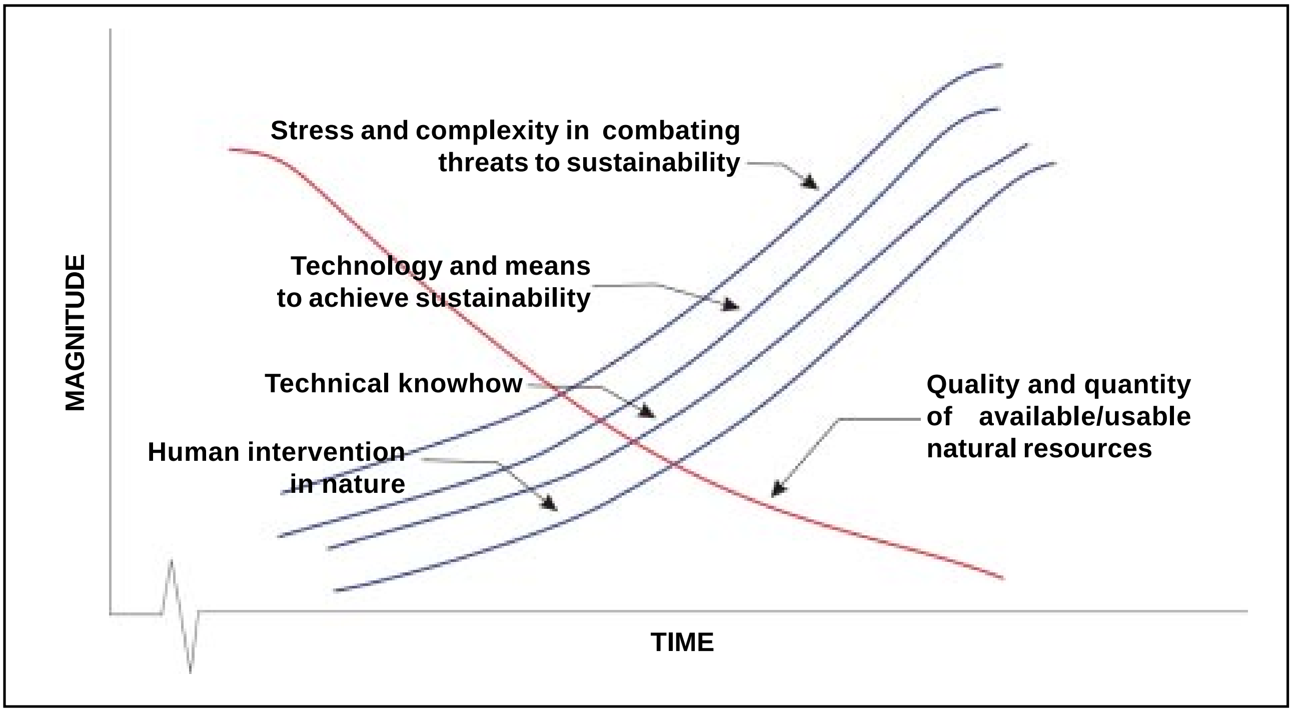
The returns to families from their production may be increased, either by reducing losses to pests (better storage and treatment) and inefficient processes (fuel-saving stoves), or by adding value before sale or use (conversion of primary products via processing). The options include post-harvest technologies; processing primary produce before sale (dried fruit, chutney, oil press, sawmills); labelling the produce for traceability and transparency (location or eco-labels); and fuel-efficient stoves.

Farm families can add value to their production through better marketing. The options include rural roads and infrastructure; farmers' markets, box schemes, farm shops and direct mailing and community-supported agriculture; producer groups for collective marketing; ethical trading schemes to ensure value accrual to rural communities and livelihoods; and green tourism schemes (selling the landscape and wildlife functions of farms).

Technologies for sustainable agriculture

A hypothetical projection of attention and seriousness required to the sustainability issue is portrayed on a time

Figure 5: A hypothetical chronological projection of attention and seriousness required to the sustainability issue



scale with relative magnitude in Figure 5. It is believed that at the current rate of growing population, mainly in developing countries, the non-renewable natural resources would be overexploited. The reserves of the resources would deplete to alarming levels, and what remains would be of deteriorated quality. With time, technology will also advance, probably causing increased human intervention in the nature. At the same time, improved technological know-how could provide a helping hand to combat threats to sustainability. However, with time, it is also believed that the sustainability issues could become more complex, and would warrant a comprehensive and multi-disciplinary approach.

Technological advancements that range from the simplest to the ones involving cutting edge ICT and satellite technologies have improved agricultural production. They have also opened up the potential for improving agriculture's sustainable base.

Best management practices (BMPs)

With the advent of biotechnological advancements, new disease-resistant hybrids, biological pest control, cultural practices that reduce the incidence of pests and diseases, and better placement and reduced amounts of fertilizers are favouring widespread-adoption of BMPs. Instead of broad-spectrum pesticides, insect-specific chemicals and biological insect controls are now commercially available. In place of overhead or flood irrigation methods, micro-irrigation (sprinklers, drips) could be used to apply water directly to roots.

Intelligent/integrated pest management (IPM) or biological control

IPM practices have greatly reduced pesticide applications and thereby the costs associated with sprays. For fruits meant for juice extraction, external appearance is of no concern. In such orhchards, one or two sprays per season of pesticide would suffice to prevent fungal diseases that affect fruit quality. Most other disease and insects that cause fruit blemishes can be ignored, as external appearance of fruit does not affect juice quality.

In contrast, for fruits sold fresh, outer appearance must meet consumers' expectations. In such orchards, pesticide sprays are required only until the economical threshold is achieved.

Intelligent placement of fertilizers

Direct placement of fertilizers to the root zone using punch-type seed and fertilizer placement devices significantly reduces fertilizer over-application. Moreover, *fertigation* – application of liquid fertilizers mixed with irrigation water – not only ensures correct placement but also lowers peak concentration of chemicals in the soil.

Precision agriculture or site-specific agriculture

Global Positioning System and Geographic Information System (GPS/GIS) help growers utilize precision agriculture by matching inputs based on actual yields of different portions on the field. Several matching equipment capable of varying applications of fertilizers and chemicals are available with GPS-enabled features. Many growers now use sprayers that turn nozzles off and on depending on field requirements. Several methodologies are commercially available to employ power of information and communication technology (ICT) with machine vision or other electronic sensors.

Variable rate technology (VRT) exhibits promising results on a field with large variability. As high as 30 per cent savings are reported with VRT-based fertilizer applicators. VRT has marked its significance not only with applicators, but also with variable rate (depth) ploughing. This saves considerable amount of drought power and undue soil disturbance.

Proven efforts for sustainable vegetable production in humid tropics

A series of collaborative efforts was made at the Asian Institute of Technology, Thailand, with the University of Hanover, Germany, and the Kasetsart University, Thailand, to ensure sustainability in vegetable production under humid tropical conditions. A protected cultivation method was adopted using plastic-roof, insect-net greenhouses.

Integrated pest management of tomato pests

Various prevailing pests (*Lepidoptera*, white flies, aphids and thrips) were controlled using biological and integrated management approach. Greenhouses fitted with 40-mesh insect net successfully lowered white fly infestation, while 78-mesh could greatly reduce thrips infestation. Moreover, an environment-friendly vector control strategy was developed.

Based on experiences in the physical exclusion of pests using insect nets with different mesh sizes, behaviour-modifying ultraviolet-absorbing plastic sheets and reflecting mulches were tested. These materials enhanced the greenhouse microclimate and disrupted the immigration and colonization behaviour of thrips. Results suggest that the type of plastic film used for greenhouse covers may influence both the initial immigration/penetration and the dispersion/distribution of certain insects in the microclimate.

Effects of greenhouses, with ultraviolet (UV) rays blocked, on the status and movement of three major pests of tomatoes – white fly, thrips and aphids – were studied. Fewer of these pests entered the greenhouses compared with the ones having high UV intensity. Consequently, significantly lower levels of leaf infestation were recorded. As compared with normal UV intensity greenhouses (with 96-100 per cent virus-infected leaves), only 6-10 per cent infection was observed in UV-blocked greenhouses.[27] In addition, the appearance of virus symptoms was remarkably delayed in UV-blocked conditions.

Use of bioactive compounds from plants has been viewed as a potential biological/botanical insecticidal approach. The extract of the neem tree (*Azadirachta indica*) has such proven insecticidal qualities. Currently, neem preparations are mainly applied as spray treatment on the crop canopy with varying levels of success in pest control. Furthermore, neem extract has several potential applications on the soil and seed too.

Adapted greenhouse systems for humid tropics

Greenhouses were constructed using regionally available materials. Design calculations considered the need to withstand high wind loads and protect plants by improving air circulation and enabling biological protection. Effect of insect net cladding on air ventilation, temperature and relative humidity was investigated in relation to their influence on plant yield, quality and protection. Air exchange rates were calculated for different mesh sizes using climate models.

A tropical climate is often characterized by heavy rainfall, humidity and high air temperature. To improve the plant condition in the greenhouse, the air temperature and humidity must be decreased to optimum levels. The minimum size of the air vents must be determined in accordance with climatic requirements. Air temperature can be decreased using infrared -reflective polythene films and white plastic mulch or white plastic pots. Additionally, forced ventilation or fan-and-pad cooling (evaporation) system can be employed. In the central plains of Thailand, greenhouses cooled with evaporative systems reduced air temperature by 2.6º-3.2ºC (day time) and 1.2º-2.3ºC (night time) and exhibited 4ºC lower maximum air temperature than mechanically ventilated greenhouses under similar environmental conditions. However, the relative humidity in such a fan-and-pad-cooled greenhouse increased by 20-30 per cent (day time) and by 10-15 per cent (night time). The water consumption of the plants significantly reduced (1.2 litres/plant/day in comparison with 1.8 litres/plant/day in mechanically ventilated greenhouses), without any fall in the plant yield (6.4 kg per plant in both types of greenhouses).

The use of shading paint containing a near-infrared reflecting pigment on the greenhouse roof reduced the air temperature by a maximum of 4ºC and lowered the transmission of global radiation inside microclimate by 18 per cent, as compared with typical greenhouses.

Nutrient recycling in tropical greenhouses

Driven by growing environmental concerns, efforts were made to develop a simple but effective nutrient recycling system for tropical insect net-cladded greenhouse. A comparison of two similar greenhouses, one with and the other without a recycling system, revealed that the recirculation of nutrient solution saved 31.5 per cent of total irrigation water. Among the major essential elements measured, the potential savings of nitrogen, phosphorous, potassium and calcium were 30 per cent, 31.5 per cent, 30 per cent and 28 per cent, respectively. The break-even of the additional cost of nutrient recycling system installation was less than five crop production cycles over a given floor area of 10 × 20 m^2. The recycling system increased water productivity by 46 per cent.

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