SUSTAINABLE DEVELOPMENT AND INTEGRATED PEST MANAGEMENT

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INTRODUCTION

Sustainable Development, as applied to agriculture and Integrated Pest Management (IPM), are complementary concepts that emerged in the last third of the 20th century. Early proponents of these concepts reflected the growing awareness of the fragility of the environment in the face of mounting human interference. Both concepts were born in controversy because, while they found broad popular appeal, there arose sharp distinctions among different constituencies as to the intrinsic meaning and practical use of the terms. Just as IPM has generated numerous interpretations and as many different definitions (Bajwa and Kogan 1996), sustainable development has been variously defined to suit the views of specific interest groups. In its broader sense sustainable development is “development that meets the needs of the present without compromising the ability of future generations to meet their own needs” (The Brundtland Report, in Conway 1993). Sustainable development, when applied to agroecosystems, was defined as “the ability of an agroecosystem to withstand disturbing forces – particularly threats to its overall productivity” (Conway 1993). This definition evokes the idea of ecosystem resilience. Sustainable development is a multidimensional concept that reaches far beyond agriculture. It permeates all levels of human endeavor, economic, social, and cultural. The following discussion attempts to focus on the broad issues of sustainability as applied to agricultural development and IPM as a fundamental component of sustainable agriculture.

The sustainability of agroecosystems is challenged by severe social, economic, and environmental problems. There are positive models of sustainable agricultural systems deployed around the world and effective IPM systems have been implemented in many countries, but the persistence of those systems themselves is threatened by the same factors that undermine the long-term sustainability of agriculture as a whole. At issue here is not just the preservation of effective methodologies of crop production or pest control. We must not only try to understand and anticipate the factors that may affect the permanence of established IPM programs, but much more importantly, consider that those same factors threaten the very integrity of the ecosphere. Most of those factors arose as consequence of the explosive growth in human population coupled with an unevenly distributed but considerably improved standard of living in many developing countries. The discussion that follows is divided into four main topics: 1. The impact of demographics on essential resources for sustainable development in agriculture; 2. Sustainable development, agriculture and IPM; 3. Anthropogenic disasters and the permanence of IPM; and 4. IPM achievements and expectations.

DEMOGRAPHICS AND SUSTAINABLE DEVELOPMENT

Between 1950 and 2000 world population increased from 2.5 to 6.1 billion, an increase of 3.6 billion. Another 2.6 billion people will be added to the planet by 2050, at a rate of 80 million per year to reach 8.9 billion. More people were added to the Earth from 1950 through 2,000 than in the 4 million preceding years since humanoids appeared on the planet (Brown 1999). Thomas Malthus in the late 18th century was one of the first to call attention to the potential risk in the disparity between population growth rates and rates of increase in food production. Technological developments of the 19th and 20th centuries may have postponed the day that Malthusian predictions became a reality. But, the carrying capacity of the Earth is limited and, in many parts of the world, we are quickly exceeding it and irreversibly exhausting key finite resources. The population issue has been amply debated since Paul Erhlich’s 1968 publication of the “Population Bomb”. Relevant demographic figures that have potential impact on sustainability have been summarized (Brown 1999, FAO 1999). Essentially demographics determine the pressure to increase food production, which in turn leads to the often unsustainable use of fundamental resources for food production – land, water, and energy.

SUSTAINABLE DEVELOPMENT, AGRICULTURE, AND IPM

The need to adopt a sustainable approach to development stems from both affluence and poverty. Affluent societies tend to over-exploit resources through excessive consumerism and waste. Poverty and under development, on the other hand, exacerbate environmental degradation often as the only short term solution to survival. Sustainable agriculture (SA) is an obvious extension of the more inclusive concept of sustainable development. The American Society of Agronomy defines a sustainable agriculture as one that “over the long term, enhances environmental quality and the resource base on which agriculture depends; provides for basic human food and fiber needs; is economically viable; and enhances the quality of life of farmers and society as a whole” .
Five guiding principles and goals have been proposed for the sustainable management of agroecosystems: “a sustainable agriculture system a) is based on the prudent use of renewable and/or recyclable resources; b) protects the integrity of natural systems so that natural resources are continually regenerated; c) improves the quality of life of individuals and communities; d) is profitable; e) is guided by a land ethic that considers the long-term good of all members of the land community. An agroecosystem is a dynamic interdependent community composed of soil, water, air and biotic species. All parts are important because they contribute to the whole” (Cavanaugh-Grant 1999). These principles generally coincide with the basic tenets of IPM.

With a theoretical foundation in agroecology (Altieri 1987, Gliessman 1990), proponents of the sustainability concept for crop production have found great affinity with the principles and approaches of IPM. Indeed, IPM provided both a conceptual and an implementation paradigm for SA. From an IPM perspective, the concept of SA provides a platform for propelling IPM to higher levels of integration (Kogan 1998). Entomologists seem to have had priority in the use of the terms "Integrated Management" when they coined the expression IPM in 1972 (Kogan, 1998). Since then the concept of integrated management received widespread acceptance in a range of agricultural, industrial, and social activities. It is fundamental to SA. Figure 1 depicts the relationships of the components of a crop or livestock production system, suggesting that the whole system, as well as its components, is under integrated management. A key feature of the integrated management paradigm is the analysis of benefits and costs of management decisions. Sustainability increases along a continuum depending on whether the costs and benefits are limited to the farm enterprise, or whether they also include values for societal and environmental costs and benefits. There are difficulties in setting monetary values for environmental and social (Turner and Pearce 1993) but once the methodologies are agreed upon they will be equally applicable to SA and to IPM decision making.

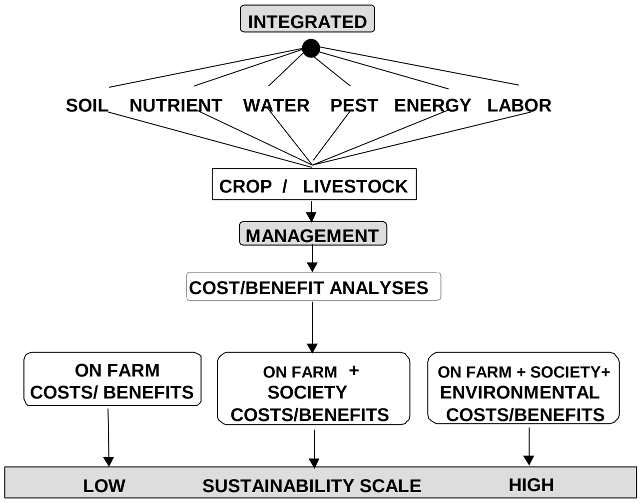

Figure 1. Integration of management components in an agricultural system.

IPM and Food Production: Increased food production was the highest priority at the end of World War II. With pest (insect, plant pathogen, and weed) damage accounting for over 30% of losses in total agricultural production, pre- and post harvest, plant protection specialists and producers were eager to adopt any new technology that had potential to reduce those losses. That technology was assumed to be the newly discovered organo-synthetic pesticides. It is estimated that since 1947 2.985 billion kg of chlorinated hydrocarbon insecticides were used. Initial results were spectacular leading to predictions that "some pests will become extinct". Early on, there was little awareness or concern about the possible side effects of what would become one of the most pervasive intrusions of man-made chemical molecules into the environment. Early success overshadowed obvious signs of problems and abuses. The need to keep food production apace with population growth overwhelmed any environmental considerations. Success of the green revolution varieties was to a large extent dependent on the availability of insecticides, as many of those varieties were susceptible to insect pests and pathogens. The health and environmental risks of the heavy reliance on pesticides were, however, too real to ignore. Rachel Carlson's 1962 book was a wake up call that helped concerned scientists more aggressively pursue the path that led, 10 years later, to establishment of IPM. Despite recent advances in pest control technologies and IPM program expansion worldwide, world crops in the 1990s still suffered up to 30 percent losses to the aggregate impact of pre- and post-harvest pests, a level similar to those suffered at the beginning of the century (Schwartz & Klassen 1981). These losses persist even while pesticide use continues to rise worldwide.

ANTHROPOGENIC DISASTERS AND THE SUSTAINABILITY OF IPM

IPM programs, by definition, should tend to be sustainable, despite the need to resort to inputs that are energy demanding, e.g., pesticides, motorized sprayers, complex synthetic semiochemicals, to mention only a few (Pimentel and Pimentel 1996). After almost 30 years of IPM implementation, there is an impressive record of achievements documented in many publications (Kogan 1998). The permanence (=sustainability) of these programs, however, is threatened by the same environmental, social, and economic pressures that also threaten the sustainability of agriculture. Those pressures stem from resource limitations, from human generated (anthropogenic) environmental disasters, and from societal pressures.

Impact of Resource Limitations: The pressure that rising populations exert on all components of an agricultural production system -- air, land, water, and energy --have a direct impact on the sustainability of IPM. Plants growing on sub-standard soils are stressed and usually susceptible to insect pests and diseases and are less competitive against invading weeds (Dale 1988, Heinrichs 1988). Scarce water supplies force growers to increase intervals between irrigation cycles or reduce the amount of irrigation; water stressed plants exacerbate arthropod pests (Holtzer 1988). Energy enters the IPM equation through equipment, monitoring equipment, pesticides. The potential indirect effect of shortages would be felt through price increases for essential inputs. Cost already is a limiting factor on crops of a few developing countries of Africa where pesticides are needed as part of the IPM system

(Abate 1996). Thus resource limitations that add to plant stress or impede use of desired IPM tactics tend to aggravate the impact of insect pests and may eventually set back established IPM programs. However, the most serious impacts on the sustainability of IPM systems come from human activities that are independent of demography, albeit magnified by population pressures.

Impact of Anthropogenic Disasters: Despite available scientific means, it has been difficult to anticipate environmental disasters. The best models of natural phenomena behavior tend to be linear and rather simplistic. Yet, nature is complex and full of surprises (Bright 2000). Small incremental changes suddenly result in a major catastrophe. Events in Honduras illustrate the convergence of multiple factors such as shifting land use, climate change, overuse of pesticides, deforestation, and malaria epidemics, coupled with natural meteorological events (hurricanes) to magnify environmental disasters as well as social calamity. The anthropogenic disasters that potentially impact on IPM systems may be grouped into two categories: a) those resulting from shifting environmental pressures, and b) those resulting from shifting social pressures.

Shifting Environmental Pressures: Examples of disruptive environmental phenomena are climate change, biological invasions, and loss of biodiversity.

Climate change no longer is a matter of opinion or speculation. Of concern now is the assessment of the extent of the changes and their potential impacts. Expected consequences of global warming trends include a shifting of climatic zones, changes in species composition and productivity of ecosystems, increases in extreme weather events, and impacts on human health (UNEP 2000). Atmospheric CO2 concentration, a major contributor to the greenhouse effect, has been both negatively and positively affected by agriculture. Negative effects include: a) changing the amount of carbon stored in the vegetation of terrestrial ecosystems (deforestation and reforestation) and in soils, b) burning fossil fuels in all phases of agricultural production and associated industries. Potentially positive effects are: a) providing renewable energy resources to substitute for fossil fuels, e.g., sugar-cane for ethanol production, and b) producing energy from biomass that recycles carbon rather than allowing it to be released to the atmosphere (Pimentel and Pimentel 1996). In addition to the direct effect on climate, the increase in atmospheric CO2 concentrations affects several plant and ecosystem processes, in turn capable of magnifying the "greenhouse" effect.

Fruit IPM in the USA offers an example of potential impact of climate change. Fruit IPM has reached a high level of sophistication and adoption among producers (Prokopy and Croft 1994). The codling moth, *Cydia pomonella* (L), is a key pest of apples, pears, and other fruit and nut tree-crops. Its management is based on accurate monitoring following a biofix date and events predicted by phenology models. The pest usually has one and a half or two generations per year. A yearly increase of but 2^{o} C in average daily temperatures would cause a third generation to occur forcing growers to spray exactly at the time when fruit is closer to harvest and spray restrictions are most strict. Such warming trend in the region could derail one of the most advanced IPM systems in the USA.

Biological invasions have increased with globalization of trade and intensification of tourism. The potential economic impact of invasive species is not only when they becomes pests, but also results from restrictions imposed on imports by quarantine regulations. A comprehensive assessment of the number and frequency of invasions worldwide would be difficult. There are, however, useful regional studies that provide a basis for extrapolating to other parts of the world. These provide an approximation of the magnitude of the problem (Kiritani 1999, Wilson 1983, OTA 1993). According to Sailer (1983) of the over 2000 non-indigenous insects introduced into the USA, intentionally or not, 235 species have become serious agricultural and forestry pests having caused cumulative losses of about 92.6 billion dollars between 1906 and 1991 (OTA 1993). Invasive species can seriously impact established IPM systems. The 1980s' invasion of Brazilian cotton fields in São Paulo and Paraná by the boll weevil, *Anthonomus grandis grandis* Boheman, set back established IPM systems at the time.

Loss of biodiversity is associated with the gradual destruction of natural ecosystems both marine and terrestrial, biological invasions, pollution, and over-hunting. The GEO-2000 report states that "At the broadest level, biodiversity loss is driven by economic systems and policies that fail to value properly the environment and its resources, legal and institutional systems that promote unsustainable exploitation, and inequity in ownership and access to natural resources, including the benefits from their use. While some species are under direct threat, for example from hunting, poaching and illegal trade, the major threats come from changes in land use leading to the destruction, alteration or fragmentation of habitats." For example, two-thirds of Asian wildlife habitats have been destroyed with the most acute losses in the Indian sub-continent, China, Vietnam and Thailand and, in the Latin American region, the average annual deforestation rate during 1990–95 was 2.1 per cent in Central and South America (UNEP 2000). It has been suggested that we live "amid the greatest extinction of plant and animal life since the dinosaurs disappeared some 65 million years ago, with species losses at 100 to 1000 times the natural rate" (Brown 1999).

In addition to the loss in species diversity, food crops around the world face an alarming narrowing of genetic diversity. With advent of high yielding varieties associated with the "green revolution" many local races were replaced by new varieties. China reduced the number of planted wheat varieties from ca. 10,000 in 1949 to ca. 1,000 in the 1970s' (Brown 1999). Both loss of traditional land-races and loss of wild relatives make breeding of new varieties increasingly dependent on a restricted genetic base. From an IPM perspective, the loss of genetic diversity increases crop plants' susceptibility to insects and diseases and reduces the chances for incorporating host plant resistance as a component of IPM systems.

The relationship between biodiversity and stability of ecosystems is still being debated in ecological circles (Schowalter 2000). The debate has a direct bearing on the argument about the importance of biodiversity for IPM. Altieri (1993) defends the argument that “biodiversity is a salient feature of traditional farming systems in developing countries and performs a variety of renewal processes and ecological services in agroecosystems.” He argues that it is important to understand the role biodiversity plays in reducing pest problems, when vegetation management is used as a basic tactic in small-scale sustainable agriculture. Altieri concludes that “the ensemble of traditional crop protection practices used by indigenous farmers represents a rich resource for modern workers seeking to create IPM systems that are well adapted to the agroecological, cultural and socio-economic circumstances facing small farmers throughout the developing world.”

Impact of Shifting Societal Pressures: Established IPM systems also are vulnerable to pressures that derive from real or perceived societal problems with pests and the techniques used for their management. Examples of such pressures are: 1. concerns about the safety of food supplies, particularly to infants; 2. the public debate about the introduction of genetically modified organisms (GMOs’) in agriculture; and 3. the intermittent and often muffled rural/urban conflict.

Food safety is monitored by several U.S. agencies. Analyses of over 8500 samples in 1998 showed no residues in 64.9 percent of domestic samples and 68.1 percent in import samples. None of the samples of grains, grain products, fruits, or vegetables had detectable residues above levels that violate current limits (FDA 1999). The food supply appeared to be reasonably safe. Yet, whether real or perceived, public pressure in developed countries has led regulatory agencies to revise existing standards for food safety. Meanwhile, in most developing countries of the world the plight of chronic starvation often overwhelms any concern about food safety.

In the USA the revision of food safety standards produced new guidelines usually known as the “Food Quality Protection Act” (FQPA) of 1996. The potential impact of these new regulatory laws on current IPM programs in the short run may be potentially disruptive. For example, removal of OPs’ for use in fruit crops may increase incidence of codling moth and reduce effectiveness of established mating disruption programs. In the long run, however, FQPA may force producers and researchers to look hard for alternatives and propel IPM to higher levels of adoption and integration

Genetically modified organisms (GMOs’) were met with a mix of excitement, controversy, and skepticism. The advent of cotton, potato, soybean, and other major crop varieties genetically modified to incorporate ?-endotoxin-producing genes of the bacterium *Bacillus thurigiensis* was heralded by some as the next silver bullet in agricultural pest control. The level and tone of the criticism, however, has exceeded expectations. Is there is a place for GMOs’ in IPM systems? It is questionable whether GMOs’ will be the silver bullet that some have anticipated. It is likely, also, that they are not the Pandora’s box that some fear to open. The true role of GMO’s will probably be as yet another tactic in the IPM arsenal that if used wisely will provide new and potentially powerful strategic options. It is essential to remember that “integration” is the key term in the IPM equation. If GMOs’ are carefully integrated within IPM systems, taking into account resistance management prescriptions, interactions with other control tactics, and careful monitoring of undesirable side effects, all within the context of ecosystem integrity, then the answer to the question is an emphatic YES, there is a place for GMOs’ in IPM systems.

The urban/rural dichotomy often is cause for friction and misunderstanding. Generations of urbanites, growing up in huge megalopolises, distant from rural areas, are generally oblivious of the intricacies of how food is produced. The lack of understanding of farming practices and intensive marketing lead grocery shoppers in big cities to demand fresh produce both unblemished and free of chemical residues. In many instances, cosmetic standards alone determine the level of pesticide use in a crop. Organic farming is helping educate the public that a certain amount of bruising in an apple or a few aphids in a head of broccoli are acceptable. This lack of understanding is a key factor in the slow adoption of IPM practices, if they fall short of guaranteeing the desired cosmetic standards. Food exporting countries of the third world must abide by the standards of their import markets. Even if farmers would adopt IPM practices for the local market, they would still be pressured to rely on chemicals for the export market.

Other areas of potential rural/urban conflict that impact IPM systems are the acceptance of the need to prevent biological invasions through eradication of incipient infestations of potentially serious pests. Large urban areas in the USA Pacific Northwest must be occasionally sprayed to eradicate nuclei of gypsy moth infestations. Eggs often hitchhike on trailers and campers of cross-country vacationers. Should the gypsy moth become established in the highly forested region, the result would be disastrous and a real challenge to pest managers. Authorities in charge of spray programs are often the target of irate urbanite critics who often misunderstand the nature of the problem and the safe nature of the approach. At the interface of city and farm other problems arise. In fruit growing areas of Oregon and Washington, for instance, it is common to find backyard grown apple and pear trees. Management of these isolated trees is often deficient allowing them to become reservoirs of insect pests and diseases that spread to adjacent commercial orchards. These three aspects of the urban/rural dichotomy serve to demonstrate that IPM within the broader context of sustainable agriculture, must encompass society as a whole. When this is achieved then IPM is truly moving toward higher levels of integration.

IPM ACHIEVEMENTS AND EXPECTATIONS:

The concept of "sustainability" is relative because it all depends on a time scale. Even if agriculture has been practiced for at least 10,000 years in some parts of the world, this represents but a brief moment in evolutionary time. Yet, even in this relatively short time span, we have witnessed the consequences of failing to consider the fragility of the environment and the disruptive impact of agriculture to natural ecosystems. IPM has the potential to demonstrate that humans can reach the level of agricultural production needed to feed the 8 billion people expected to inhabit the planet in 2050, and still maintain harmony with the environment. If, through effective IPM, we can reduce the over 30 percent annual production losses to pests, we would be contributing an additional 750 million tons of food grains, enough to feed 1.8 billion people at an adequate level of 400 kg per year. To reach this goal there have been some remarkable achievements in the development of new environmentally benign control tactics that can replace more disruptive tactics. We have been less creative in the advancement of new strategic approaches. Areawide IPM is a recent example of what can be accomplished with a modest strategic shift. Sustainable agriculture, like IPM, also needs a strategic leap. Both IPM and SA seem to remain at level I of integration, i.e., a narrow focus on single crops or limited mixed cropping systems, within small agroecological units (small farms or microregions). Models that consider entire ecological regions are rare. When SA adopts the ecoregion as the fundamental planning unit, then IPM also will have reached level III integration, because at this level the two approaches to agricultural development will be indistinguishable.

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