

CONSULTATIVE GROUP ON INTERNATIONAL AGRICULTURAL RESEARCH
TECHNICAL ADVISORY COMMITTEE

Environmental impacts of productivity-enhancing crop research:
A critical review

TAC SECRETARIAT
FOOD AND AGRICULTURE ORGANIZATION OF THE UNITED NATIONS

CONSULTATIVE GROUP ON INTERNATIONAL AGRICULTURAL RESEARCH
TECHNICAL ADVISORY COMMITTEE AND CGIAR SECRETARIAT

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A report from

TAC's Standing Panel on Impact Assessment (SPIA)

TAC SECRETARIAT

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SPIA Foreword

At the TAC/SPIA impact assessment workshop held in May 2000 (TAC/SPIA, forthcoming), there was considerable debate about the evidence concerning negative impacts of Green Revolution (GR) technologies. The general conclusion reached was that there is a lot of literature on the subject, but what was lacking was one document that summarizes past documentation on impacts and provides an objective synthesis of ideas and conclusions coming out of the literature. The workshop participants strongly recommended that SPIA undertake such a study, focusing on the negative externalities associated with crop technologies. The report that follows is the result of a subsequent effort of SPIA.

This study was carried out by Drs. Mywish Maredia and Prabhu Pingali. Dr. Maredia was a member of TAC/SPIA's independent panel for the study on environmental impacts of CGIAR research and related activities (see Nelson and Maredia forthcoming). Dr. Pingali is Director of the Economics Program at CIMMYT and has for many years been studying the impacts of the CGIAR and its research.

There is a large body of literature that focuses on the negative externalities and environmental impacts associated with agriculture and modern technologies. This study brings together the evidence from the literature related to the nature and magnitude of environmental impacts of productivity-enhancing technologies, presents some estimates of negative impact (i.e., reduction in land saving) due to its introduction and adoption, and notes the CGIAR's successes and failures in mitigating some identifiable external effects. A central purpose of the paper is to link environmental impacts to research. However, tracing the link from impact to research is difficult, if not impossible, because there are so many other factors that enter the picture, and because many environmental problems observed today have nothing to do with the technologies developed through research in the sixties and seventies. The paper discusses the difficulty inherent in establishing counterfactual scenarios in the context of assessing the environmental impacts of research.

SPIA is pleased with the output of this study, which we hope will make a significant contribution to the literature related to impacts of agricultural technology and research. As new approaches are developed and technology evolves, along with a better understanding of the negative impacts associated with present and past technologies, we are likely to see more research on ways of mitigating negative environmental impacts. A first step in setting the course for development of the more environment-friendly agriculture is to dig below the surface of the myths, exaggerations, and unsupported contentions surrounding the environmental impacts of agriculture. SPIA believes that this study helps us to take this first, important step.

Hans M. Gregersen
Chair
TAC's Standing Panel on Impact Assessment

CONSULTATIVE GROUP ON INTERNATIONAL AGRICULTURAL RESEARCH
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**Environmental Impacts of Productivity-Enhancing Crop Research:
A Critical Review**

Study Panel: Dr. Mywish Maredia
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TAC SECRETARIAT
FOOD AND AGRICULTURE ORGANIZATION OF THE UNITED NATIONS
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Executive Summary

The purpose of this paper is to critically review the available evidence and empirical findings of negative environmental impacts resulting from intensification and productivity-enhancing technologies. The objectives of the paper are to present and discuss: 1) the environmental problems associated with modern crop technologies, and the evidence of “research-to-impacts” linkages found in the literature; 2) the empirical evidence of estimates of environmental impacts of specific externalities associated with productivity-enhancing technologies; 3) the corrective steps taken (or not taken) by the CGIAR to mitigate some of the high externality risks of improved crop technologies; and 4) the problems and possibilities of attributing environmental impacts to research by examining the factors that contribute to negative externalities and the conceptual and methodological issues related to impact assessment.

Major externalities associated with the yield-enhancing technologies and the use of chemical inputs include:

- Concerns about the loss of gene pools (or “genetic erosion”) in centers of crop diversity and the narrowing of the genetic base as a result of monoculture.
- Soil fertility problems (such as declining soil nitrogen supply, micro-nutrient deficiencies and soil toxicities, long-term changes in soil physical characteristics) as a result of widespread adoption of high-yielding varieties of food crops and intensification.
- Increased vulnerability of crops to insect pests and diseases, which has led to increased pesticide use and contributed to increases in production costs, human health hazards, contamination of soils, food, surface and ground water, pest resistance, pest resurgence, and development of secondary pests.
- The problem of waterlogged soils and a rise in water tables, which in arid and semi-arid areas has caused soil salinity problems, reduced yields and abandonment of land.
- The problem of lowering water table levels and/or dry wells in many parts of the developing world as a result of excessive irrigation.
- Concerns of ground and surface water pollution, air pollution, crop damage, and damage to soils by destruction of the natural N-cycle resulting from excessive fertilizer application.
- Concerns for changes in weed ecology and possible emergence of herbicide resistance as a result of increasing use of herbicides and the shift from transplanting to direct seeding.
- Concerns of expanding crop cultivation to new areas, many of which are environmentally fragile and easily degraded.

The evidence related to the nature and magnitude of negative environmental impacts of productivity-enhancing technologies includes: soil degradation impacts, human health impacts, and impacts associated with loss of genetic diversity. Aggregate cost estimates of these externalities in developing and industrialized countries are presented, where appropriate, to give an idea of the scale and magnitude of environmental costs of modern agricultural technologies. The review of such evidence indicates that: (1) with the exception of salinity problems associated with irrigation, the loss of soil fertility associated with monoculture, and the health impacts of pesticides, the negative externality problems and their environmental impacts are not well documented; (2) it is difficult in most cases to move

from examples to aggregate global estimates of negative impacts; (3) the conceptual and measurement issues in estimating the monetary values (associated with impacts) are too complicated to derive any meaningful estimates of aggregate environmental costs; and (4) an appropriate measure of such impacts is reduced “land savings” or the counterpart to the positive environmental impact associated with productivity-enhancing technologies, namely “land savings” achieved. Due to irrigation-induced soil salinity problems in developing countries, total reduction in “land savings” (or augmentation in land-use) is estimated to be in the range of 20 million hectares in the late 1990s. In other words, the cropping area required to produce the same output as on the existing irrigated land, with either ‘light’ or ‘moderate’ salinity problems and abandoned due to or ‘extreme’ salinity degradation, would be 20 million hectares less than the cropping area in the late 1990s.

The concept of “land savings” foregone is applied to estimate the impacts for other soil fertility problems resulting from monoculture and intensification. Based on other's ball-park estimates of degradation problems, land lost to degradation (other than for salinity) is estimated to be on the order of 70-80 million ha globally. This is several hundreds of millions of ha. less than the Nelson-Maredia estimates of land savings associated with CGIAR research on eight of its main mandated crops.

Recognition of the actual or potential natural resource degradation and its consequences for human well-being have triggered a number of remedial responses from the CGIAR-NARS research partnerships. These include research on the development of pest-resistant varieties (host plant resistance) and integrated pest management (IPM). However, while progress has been significant in terms of IPM and breeding of host resistant plants, the corresponding reduction in need for pesticides has not been adequately publicized. The continued high and injudicious insecticide applications by farmers has led to the frequent breakdown in varietal resistance, and consequently repeated application of pesticides. Other environmental concerns, to which the CGIAR did not respond rapidly, include the soil salinity problem and the reduction of herbicides. The research system response to the salinity problem was to develop salt-tolerant varieties. Such an approach did not solve the salinity problem, however, it only changed the slope of the crop-yield response curve to salt-affected soils through making the crop cultivable to saline soils. Finding cost-effective mechanisms for reducing herbicide use in cereal crops remains a challenge for the research and policy community.

The challenge for the environmental impact assessment of productivity-enhancing research is to analyse and measure the effects beyond those relating to productivity. This means quantifying the positive and negative externalities and assessing the environmental impacts of these externality effects. The conclusions emerging from this review indicate the difficulty and complexity involved in determining the counterfactual and attributing the impacts to agricultural research. There are two main reasons for this. Firstly, factors other than technology (i.e., technological and economic change, social and political policies) have played an important role in creating the environmental problems. Secondly, many of the problems of negative externalities observed today and discussed in the literature have nothing to do with new technologies resulting from agricultural research (such as the Green Revolution technologies in the 1960s and 1970s). The underlying causes of agricultural intensification are usually multifactorial. For example, the problems associated with intensive use of irrigation would have occurred without the use of modern varieties or other inputs. The paper presents evidence that supports both these arguments.

One option for attributing environmental costs to past research efforts is to consider the contribution of mainstream research in the context of augmenting the rate of increase in the intensive use of inputs such as fertilizers, pesticides and irrigation. For ex post assessment of environmental costs this will involve constructing a “without” technology scenario based on input observations lagged by “n” number of years, where “n” is to be determined after a careful examination of technical and policy factors for a given input on a case-by-case basis. Alternatively, estimates of counterfactuals can be derived using a general equilibrium framework and modeling input use (HYVs, irrigation, fertilizers, pesticides) as functions of different technical, economic and policy variables, and relating them with an associated measure of externalities at different levels of input use.

Several conclusions emerge from the review of literature related to the negative externalities associated with monoculture and the increased intensity of “external” input use — irrigated water, fertilizers, and pesticides. These are:

1. The literature shows very little scientific evidence to back up 'claims' about the negative environmental impacts of crop improvement technologies.
2. In cases where there is evidence linking technology components with negative environmental impacts (e.g. for soil salinity), it is difficult, if not impossible, to trace the link from impact to research, mainly because there are many other factors entering the picture that confound attempts to make direct links. Also, many environmental problems observed today have nothing to do with the technologies developed through research in the sixties and seventies.
3. Evidence of negative environmental impacts has only been presented in the literature for a few Green Revolution crops, mainly wheat and rice, yet the CGIAR works on many other crops. There is hardly any evidence of negative environmental impacts from improved technologies from these other crops.
4. Because of the bias towards wheat and rice in the documentation of externality problems, it is difficult to separate the negative impacts associated with the Green Revolution - a product of the mainstream agricultural research (spearheaded by the CGIAR) - from the impacts of agricultural intensification, which is caused by factors other than research. The confusion between these two phenomena (Green Revolution and intensification) has led to misconceptions linking environmental degradation with agricultural research.

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Environmental Impacts of Productivity-Enhancing Crop Research: A Critical Review

1. Introduction

Global research efforts, spearheaded by the CGIAR, have resulted in biological technologies and other methods of increasing crop production for a given area of land. This has led to a substantial increase in crop production in developing countries during the past few decades and has facilitated the commercialization process of the agricultural sector. This principle of intensification enabled land to be used economically, and resulted in positive externalities in the form of the natural and semi-natural areas being safeguarded. However, the intensive use of land, fertilizers, pesticides and irrigation has had negative impacts on the environment and human health has become a highly publicized issue in agricultural development (Pingali *et al*, 1997; Pingali and Rosegrant, 1994, 1998; Postel, 1989).

There is a large body of literature that focuses on the negative externalities and environmental impacts associated with agriculture in general and modern technologies (such as high yielding varieties (HYVs), irrigation, chemical fertilizers and pesticides) in particular, both in the industrialized and developing countries (e.g. Conway and Pretty, 1991; Fernando and Thomas, 1978). The literature is replete with anecdotes, case examples and discussions of how the HYVs negatively impacted the environment and the social structure of a society. However, the literature also contains counter-arguments that the concerns about the negative externalities of intensification and agricultural research are valid but somewhat misplaced. Agricultural intensification, *per se*, need not degrade the environment¹, but mismanaged agricultural intensification and inappropriate policies are to be blamed (Pinstrup-Andersen and Pandya-Lorch, 1994; Rola and Pingali, 1993). Several studies cite examples that show that the role of HYVs in generating the negative environmental impacts is greatly overstated and point out some of the breakthroughs and outputs of modern scientific research that not only mitigate the problems but also ameliorate the environment (Byerlee, 1996; Smale, 1997; Hawkes, 1983).

The purpose of this paper is to critically review the available evidence and empirical findings of the environmental impacts, which have resulted from intensification and productivity-enhancing technologies. The focus of the paper is specifically on externalities associated with crop technologies. Rice, wheat and maize are most responsive to intensification and yield-enhancing technologies. Hence much of the evidence of negative externalities found in the literature in developing countries relate to these crops. Evidence of linkages between modern varieties, increased input use and externalities in other crops is not that strong in the literature. But we make an effort to present evidence of externalities in other CGIAR-mandated crops where possible. The focus of this paper is on negative externalities of agricultural technologies.² The paper primarily focuses on developing countries, but evidence

¹ A review of eight intensified farming systems in developing countries by Nicholas Wallis (1997) indicates that most of these intensive systems have proven effective in exploiting the natural resources upon which they are based, not degrading them, and sometimes even restoring them.

² Assessment of positive impacts, namely land saving impacts of productivity-enhancing research was the major focus of the 1999 and 2000 SPIA Reports on Environmental Impact Assessment (see e.g., Nelson and Maredda 1999).

of externality effects in industrialized countries is also cited to establish a linkage that may not have been documented as existing in developing countries.

We begin in Section 2 with a general overview of the environmental problems associated with modern crop technologies, and a general overview of the evidence of “research-to-impacts” linkages in the literature. Section 3 presents empirical evidence of estimates of environmental impacts of specific externalities associated with productivity-enhancing technologies, followed by a discussion of the corrective steps taken (or not taken) by the CGIAR to mitigate some of the high externality risks of improved crop technologies. Section 5 discusses the problems and possibilities of attributing environmental impacts to research by examining the factors that contribute to negative externalities and the conceptual and methodological issues related to impact assessment. The paper concludes with a discussion of further research needs in this area.

2. Crop Technologies and Associated Environmental Problems

The technologies examined in this paper are mainly crop technologies that have resulted from the CGIAR and NARS collaborative research efforts. More generally the crop technologies can be grouped into the following three types:

- **Yield-enhancing technologies.** These include the HYVs, which are associated with the practice of monoculture¹ and increased reliance on irrigation and inorganic fertilizers.
- **Variability reducing technologies.** These include pesticides and alternatives such as improved crop varieties with resistance to biotic and abiotic stresses and IPM.
- **Labor saving technologies.** These include improved crop management practices and the use of inputs such as herbicides and machinery that demand less labor input.

Many of the technologies in category 2 (e.g. IPM and host plant resistant varieties) were developed by the CGIAR and NARS in direct response to the high externality risks posed by technologies in Group 1 and some earlier technologies for variability reduction, such as pesticides. This is further elaborated and discussed in Section 4. Here, we first examine the major environmental problems related to these technologies and the policy environment that encouraged input intensification.

Major externalities associated with modern crop technologies, especially with the yield-enhancing technologies and the use of chemical inputs for variability reduction and labor saving include:

- Concerns about the loss of gene pools (or “genetic erosion”) in centers of crop diversity and the narrowing of genetic base as a result of monoculture (Kloppenburg, 1988; Wilkes, 1992).
- Soil fertility problems (such as declining soil nitrogen supply, micro-nutrient deficiencies and soil toxicities, long-term changes in soil physical characteristics) as a result of

¹ Crop monoculture (or monocropping) refers to the practice of growing a single plant species in one area, usually the same type of crop grown year after year. Monocropping is generally accompanied by a trend away from inter-cropping and crop rotation. Both intensification and monoculture are frequently associated with the Green Revolution.

widespread adoption of high yielding varieties of food crops and intensification (Pingali and Rosegrant, 1998).

- Increased vulnerability of crops to insect pests and diseases,¹ which has led to increased pesticide use and contributed to increases in production costs, human health hazards, contamination of soils, food, surface and ground water, pest resistance, pest resurgence, and development of secondary pests (Pingali *et al*, 1994).
- The problem of waterlogged soils and a rise in the water tables, which in arid and semiarid areas has caused soil salinity problem, reduced yields and abandonment of land (Postel, 1989; Yudelman, 1989).
- The problem of lowering water tables and/or dry wells in many parts of the developing world as a result of excess irrigation (Postel, 1993).
- Concerns of ground and surface water pollution, air pollution, crop damage, and damage to soils by destruction of the natural N-cycle resulting from excessive fertilizer application (Conway and Pretty, 1991).
- Concerns for changes in weed ecology and possible emergence of herbicide resistance as a result of increasing use of herbicides and the shift from transplanting to direct seeding (Moody, 1994).
- Concerns of expanding crop cultivation to new areas, many of which are environmentally fragile and easily degraded. Variability-reducing technologies such as drought-tolerant varieties and varieties tolerant to acid soils are often blamed for replacing traditional crops in a farming system. For example, the new drought tolerant maize varieties in the sub-humid zones of West Africa have rapidly replaced traditional food staples of millet and sorghum (Sanders, Shapiro and Ramaswamy, 1996). It thus affects the food diversity and nutritional status of local communities.

Figure 1 summarizes the linkages between different components of the productivity-enhancing technology and the natural resource consequences and externality effects as evidenced from the literature. As the illustration shows, tracing the link between research and environmental impacts is a complex process involving many different variables and factors. Some of the links in the “research-to-impacts” chain are well established in the literature (as denoted by the dark arrow lines). For example, the negative externalities on human health of increased use of pesticides are well documented, albeit for selected crops and regions. Other linkages (denoted by softer lines and arrows) in the “research-to-impacts” chain are discussed and debated in the literature, but not well established empirically. Thus the link between research that led to the development of HYVs and the loss of genetic diversity is a weak one. Overall, there is little scientific inquiry (evidence) in support of some of the claims of negative externalities.

According to “conservationists” and critiques of mainstream agricultural research, the negative effects of agriculture on natural resources is the direct consequence of “agricultural research focused on increasing productivity and ignoring externalities (which) is largely built on technologies that maximize biological uniformity and sidestep, minimize, control or destroy the natural biological diversity which is essential to the stability and resilience of natural ecosystems” (Ashby, 2000, p. 5). According to this viewpoint, the observed negative

¹ An example often cited in the literature is the virulent fungus plague of 1970 that swept through the United States Corn Belt, spreading at up to 150 kilometers a day. United States maize production was reduced by 15 percent as a result of the fungus. However, increased research and development efforts on maize has lessened the impact of such outbreaks—the alternative varieties planted in subsequent years allowed corn yields to rise above pre-1970 levels (Crosson and Rosenberg, 1989).

Research-to-impacts chain

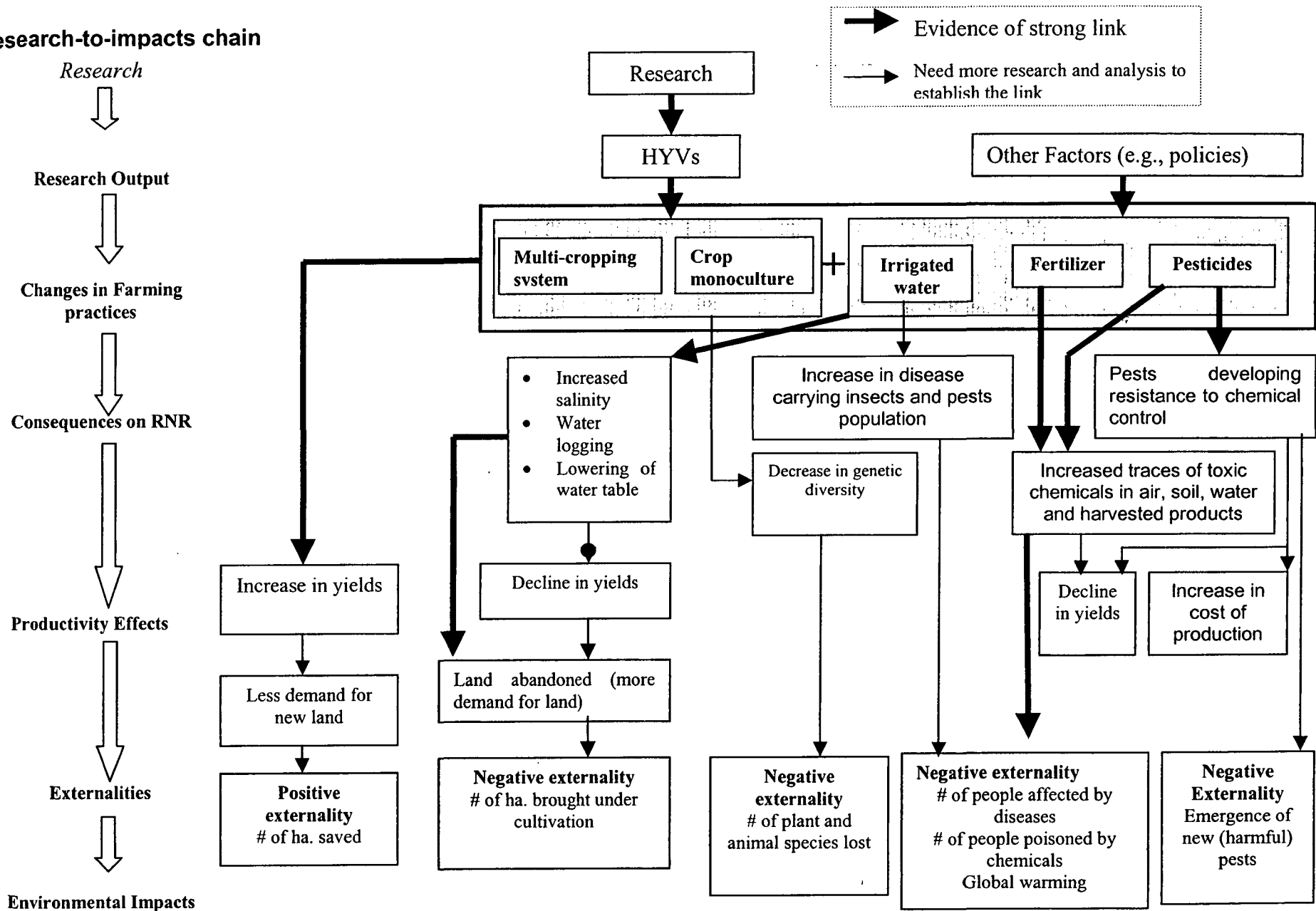


Figure 1. From research to environmental impacts: Tracing the link between different components of productivity enhancing technology and externalities generated from the literature review

impacts of intensification are ultimately to be blamed on the reductionist focus of conventional or mainstream agricultural research, which treated agriculture as a separate endeavor from the natural resource management.

However, as illustrated in Figure 1 and later elaborated in this paper the policy environment and non-technology related factors played an important role in promoting intensive use of some inputs. Several studies establish a strong link between policies and increased or overuse of some of these inputs and the subsequent consequences on renewable natural resources and externality impacts (e.g. Pingali and Rosegrant, 1994; Pinstrup-Andersen and Pandya-Lorch, 1994). One of the implications of this observation is that many of the problems of negative externalities observed today and discussed in the literature have nothing to do with new technologies that resulted from agricultural research (such as the HYVs). For example, the problems associated with intensive use of irrigation would have occurred without the use of modern varieties or other inputs. Regions in India and Pakistan where *basmati* rice (which is a traditional variety) is grown have one of the highest salinity problems today in the world. Similarly, the practice of monoculture would have gained popularity even in the absence of the Green Revolution as forces other than technology (e.g. urbanization, improved infrastructure) would have led to the commercialization of agriculture.

To evaluate the environmental impacts of agricultural research we first examine the empirical evidence found in the literature linking crop technologies with externalities and any available estimates of the environmental impacts of these technologies. The baseline against which we try to assess the negative impacts of CGIAR research is the global pattern of natural resources degradation as a result of expansion and/or intensification of irrigated and dryland agriculture. However, as suggested above (and further elaborated below) the cause of this pattern is multi-faceted. Later in the paper, we discuss the difficulty of assessing what might have occurred in the absence of CGIAR research, and note CGIAR's successes and failures in mitigating some identifiable external effects.

3. Estimates of Environmental Impacts of Productivity-Enhancing Technologies

Table 1 summarizes the overall status of evidence available in the literature on the various negative externalities linked with modern crop technologies and their environmental, health and economic impacts. With the exception of salinity problems associated with irrigation, the loss of soil fertility associated with monoculture, and the health impacts of pesticides, the evidence on the extent of the negative externality problems and their environmental impacts are not well documented. For example, evidence of water and air quality degradation, and changing levels of water tables linked with increased irrigation and chemical input use in agriculture is documented but too scattered and site-specific to enable generalizations about the global extent and impacts of these problems.

Examples of studies estimating the overall environmental/economic costs associated with negative externalities of productivity-enhancing research (listed in the last column in Table 1) at an aggregate country- or regional- level are rare in the literature. Although several attempts have been made to put approximate cost values to pollution arising from agriculture in the industrialized countries, it has generally proven difficult to do. First, it is necessary to know the value of nature's goods and services, and what happens when these are lost. Second, it is difficult to put a value on non-market goods. Environmental economists have developed

Table 1: Estimates of negative externalities of productivity-enhancing technology in developing countries: Evidence from the literature

Negative Externality	Evidence from the literature	Estimates of area/extent of a given problem	Environmental/economic implications
Loss of genetic variability	Discussed in the literature but evidence not substantiated	No quantitative estimates available	Loss of biodiversity Declining crop productivity
Salinity and water logging	Evidence of this problem in irrigated areas available and well documented.	45 M ha globally suffer from salinity and water logging problems	Land abandoned Declining land productivity
Changes in the level of water table	Evidence of both increase and decrease in water table level is found in the literature; evidence scattered and location specific	Water table increase reported in the range of 0.1 to 3.0 meters per year in some irrigated project areas. Reported water table decline range from 0.4 to 1.0 meters per year in some regions.	Declining land productivity
Loss of soil fertility/erosion	Evidence documented for rice in Asia; evidence of linkage in other crops not substantiated	No global estimates available	Declining land productivity
Water pollution	Most evidence found in developed countries; scattered evidence in LDCs	No global estimates available	Increased health costs; loss of aquatic flora and fauna
Air pollution	Discussed but not substantiated in LDCs	No global quantitative estimates available	Increased health costs; lower factor productivity
Food contamination	Scattered evidence in LDCs	No global estimates available	Increased health costs
Impacts on human and animal health	Case-specific evidence on this linkage available. Most evidence relates to pesticides and its health effects	Globally 3 million cases of pesticide poisoning each year resulting in 220,000 deaths.	Increased health costs and social/economic costs associated with lower labor productivity
Effects on pest population	Case-specific examples and scattered evidence	No global estimates available	Increased costs of production (pesticides) and declining crop productivity

methods for assessing people's stated preferences for environmental goods through hypothetical markets (see Winpenny (1991) for detailed discussion on these various methods). However, any attempt to put an overall economic or environmental cost value on the consequences of the externalities identified in the literature will necessarily be crude.¹

In this section we present evidence and empirical estimates of environmental and health impacts of three types of externalities for which there is a fair amount of evidence/discussion in the literature in the context of developing countries. These are the environmental and human health impacts associated with soil degradation (due to irrigation and monocropping), the loss of genetic diversity and the use of chemical inputs. Aggregate cost estimates of these externalities in developing and industrialized countries are presented where appropriate to give an idea of the scale and magnitude of environmental costs of modern agricultural technologies.

3.1 Environmental Impacts Associated with Soil Degradation

There are basically two categories of soil degradation. The first deals with soil degradation by displacement such as water and wind erosion and the second with the physical and chemical soil deterioration. Here we are concerned with the second type of soil degradation often associated with agriculture. It includes waterlogging, salinisation, loss of nutrient and/or organic matter, acidification and pollution/toxicity. These soil degradation problems are discussed below under two groups – soil salinity and waterlogging problems often associated with irrigation and loss of nutrient and soil fertility problems associated with the practice of monoculture and intensification.

Soil salinity and waterlogging

Waterlogging refers to the saturation of soil with water, resulting from over-irrigation, seepage or inadequate drainage. Salinisation is the increase in concentration of total dissolved solids in soil and water. Both these phenomena are linked with irrigation and have adverse effects on crop productivity. Although salinisation of land and water resources is as old as the history of human settlement and irrigation, it has increased with the intensive use of irrigation water in the past 50 years.

Estimates of the area affected by salinity vary widely. Oldeman *et al* (1991) estimated that worldwide 10.5 M ha are affected by waterlogging and 76.6 M ha are affected by human-induced salinisation, but they did not differentiate salinity in the irrigated and non-irrigated rainfed areas. Postel (1990) estimates the share of salt-affected soils for the five leading countries in area irrigated to be about 24 percent. Dregne *et al* (1991) estimated that about

¹ There have been several studies on the external costs of modern agriculture in USA and several European countries (Pimentel and Greiner 1997; Davison *et al.* 1996; Fleischer and Waibel, 1998; Bailey *et al.* 1999 all cited in Pretty *et al.* 2000). These studies suggest that total external costs are some \$81 to \$117/ha of arable and permanent pasture in Germany (only pesticides and gaseous emissions costed) and the USA, rising to \$112-\$274 for arable land only (Pretty *et al.* 2000). In UK the total external costs of agriculture are estimated to be £2,343 million or 89% of average net farm income for 1996. This aggregate is equivalent to £208/ha/year averaged across all 11.28 m ha of arable land and permanent grassland in UK (Pretty *et al.* 2000). For several reasons, however, the data and results of these studies are not wholly comparable in their original form, and methodological concerns have been raised about some studies (Bowles and Webster, 1995).

43 M ha of irrigated land in the world's dry area are affected by various processes of degradation, mainly waterlogging, salinization and alkalisation.¹

Table 2 shows the estimated salt-affected land in selected countries that represent about 70 percent of global irrigated land. These estimates are based on the survey done by Ghassemi *et al* (1995). Using the average value of the share of salt-affected land in the surveyed countries (20 percent), the authors estimate the total world-wide salt-affected lands in the irrigated area to be 45.4 M ha (Table 2). India, China, Pakistan and the Central Asian countries are the most affected by salinity in the irrigated areas. The major causes of salt-induced soil degradation in the countries surveyed were excessive irrigation and lack of drainage facilities. Taking the estimates of Oldeman *et al* (1991) of total salt affected area of 76 M ha worldwide and their own estimate of 45.4 M ha in irrigated areas, Ghassemi *et al* (1995) attribute a total of 31.2 M ha of non-irrigated lands to human-induced salinisation.

So what are the environmental and human health impacts of soils affected by salts and waterlogging? Waterlogging, which is the forerunner of land salinisation in many cases, damages plant growth by creating an imbalance in the amount of air (oxygen) and water in the soil. Salinisation and alkalisation in their early stages of development reduce soil productivity, but in advanced stages kill all vegetation and consequently transform fertile and productive land to barren land. Thus the two major environmental impacts of waterlogging and salt-affected soils are the decline in crop productivity and loss of arable land, which leads to loss of habitat and reduction of biodiversity. Empirical evidence and economic estimates of these impacts are available for some study areas and are discussed below. Salt-affected soils can also have (indirect) human health impacts as they severely limit the choice of crops², reducing crop diversity and adversely affecting diets and nutritional status of rural people. However, there is no empirical evidence or estimates of impacts of the changes in cropping systems on human health and nutrition, except for documenting the changes that have taken place over the long-term on the crop diversity of a region (e.g. in Punjab, India)³ (Brar, 1999).

The impact of salt-affected soils on crop yields is well documented based on experimental trials. Figure 2, for example, indicates the sensitivity of a range of important crops to soil salinity. Thus, crops like beans and maize are relatively more sensitive to salt-affected soils as they experience yield losses at a lower measures of soil salinity than more tolerant crops like wheat and barley. Table 3 shows the effect of irrigation water on crop yields under different cropping system observed at the Chandra Sekhar Azad University of Agriculture and Technology Seed Farms in Kanpur, India. The data show the sensitivity of different crops' yielding ability to the intensity of irrigation and crop rotations. Pulses such as mung beans and pigeon peas were relatively more sensitive to salinity than cereal crops. In general, higher cropping intensity and irrigation frequency was associated with greater yield losses over the period 1974-75 to 1989-90.

¹ Alkalisation refers to the accumulation of sodium in soil or water to a level that causes degradation. In the literature, alkaline soils are classified as "salt-affected" soils along with saline soils.

² Food crops tolerant or moderately tolerant to salinity include grains such as barley and wheat. Food crops such as beans, maize, and many vegetable crops are sensitive or moderately sensitive to salinity. Thus when soils are affected by salinity, these crops are first to be eliminated from local cropping systems and replaced with more tolerant grain crops like barley and wheat.

³ It should be noted, however, that the main cause of declining crop diversity in the Indian Punjab was not soil salinity but the economic policy support given to growing rice and wheat relative to other alternative crops.

Table 2: Extent of salinity problem and its major causes: Summary data for selected countries, 1980s

Country	Cultivated land (M ha.)		Irrigation- induced salinity (M ha.)	Main affected areas	Major causes
	Total	Irrigated			
Developing countries/regions					
Argentina	35.8	1.5	0.58	San Juan, Mendoza, Salta and Rio Negro Provinces	Extensive irrigation without drainage facilities
China	100.0	48.0	6.7	Huang-Huai-Hai Plain	Extensive irrigation without drainage facilities
Central Asian countries (CIS)	232.6	20.5	3.7	Central Asia, Ukraine, Caucasus region and Volga Basin	Extensive irrigation without drainage facilities
Egypt	2.7	2.7	0.8	Nile Valley and Delta	Extensive perennial irrigation
India	169.0	42.1	7.0	Punjab, Haryana, Uttar Pradesh, Bihar, Rajasthan and Madhya Pradesh	Extensive irrigation without drainage facilities
Iran	14.8	5.7	1.7	Many irrigation projects including: Zarrineh-Rud, Moghan, Khalafabad, Doroudzan and Zayandeh-Rud	Inadequate irrigation and drainage facilities, irrigation with low quality water
Mexico	24.7	5.0	0.5	Northern states	
Pakistan	20.8	16.1	4.2	Indus River Basin	Extensive use of surface water for irrigation and inadequate drainage
South Africa	13.2	1.1	0.1	Breede, Berg, Great Fish and Sundays River Basins	Irrigaiton on soils with subsurface salt contents
Thailand	20.0	4.0	0.4	Khorat and Sakon Nakhon Basins in Khorat Plateau. Lam Pao and Nong Wal irrigated areas	Land clearing, reservoir construction, salt making and irrigation

Table 2 Cont'd.

Country	Cultivated land (M ha.)		Irrigation- induced salinity (M ha.)	Main affected areas	Major causes
	Total	Irrigated			
Developed countries/regions					
Australia	47.1	1.8	0.16	Murray Basin, south-west of Western Australia, and South Australia	Land clearing, extensive irrigation, construction of hydraulic structures
USA	189.9	18.7	4.16	Colorado River Basin, San Joaquin Valley, Lower Rio Grande and Northern Great Plains	Excessive irrigation without adequate drainage facilities
WORLD	1473.7	227.11	45.4 ^a	Arid and semiarid regions of the world	Excessive irrigation without adequate drainage facilities and land clearing for agricultural development and grazing

Source: For all countries except Mexico: Ghassemi, Jakeman and Nix (1995) – Appendix 1. For Mexico: Umali (1993) Table 3.1

^a Based on the assumption of 20% irrigated area affected by salinity, which is the average share of irrigation-induced salinity area in the countries listed in this table (these countries represent about 70% of world's irrigated land).

Table 3: Effect of irrigation water on crop yields in the period 1974-75 to 1989-90 at the Chadra Sekhar Azad University of Agriculture and Technology Seed Farms, Kanpur, India

Crop rotation ^a	Crops	No. of irrigations per year	Crop yield (t/ha)		Yield reduction (%)
			1974-75	1989-90	
Pigeonpea-fallow	Pigeonpea	1	0.15	0.12	20
Mung bean-wheat	Mung bean	1	0.05	0.02	60
	Wheat	5	4.00	3.00	25
Rice-Wheat/Potato	Rice	6	4.00	3.00	25
	Wheat	5	4.00	2.50	38
	Potato	7	30.00	15.00	50
Irrigation water quality: Ecw 1.2 dS/m; pH 8.2; SARw 9 (mmol/l) ^{1/2} ; RSC 9.4 meq/l					

Source: Gupta and Arbol (2000), Table 6.

^a Annual rainfall 765 mm.

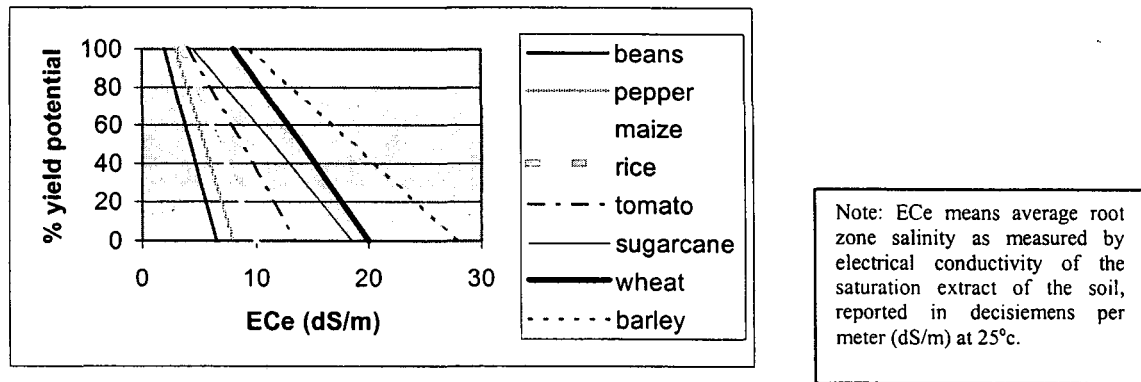


Figure 2: Yield sensitivity of selected crops to soil salinity (measured by Ece)

Source: Ayers and Westcot (1985)

There are few comprehensive studies of farm-level effects of irrigation-induced salinity. In one study conducted by Joshi and Jha (1991) in the Sharda Sahayak irrigation project in India, the authors found that the yields of paddy and wheat were 41-56 percent lower on the degraded soils and net incomes in salt-affected lands were 82-97 percent lower than the unaffected land. Productivity losses were a result of increased costs of production: the per unit costs for paddy rose by about 60 percent, while for wheat per unit costs increased by about 85 percent in saline lands. Using decomposition analysis, the study found that salinity accounted for as much as 72 percent of the difference in gross income between normal and salt-affected plots. The study also found that farmers reverted to low-input traditional varieties and practices as soil conditions deteriorated.

Similarly, a study conducted in the Menemem irrigation and drainage project in Izmir, Turkey, found the average net returns per ha for cotton and paddy production to be 42 and 35 percent of the net returns in the unaffected areas (Republic of Turkey 1990 cited in Umali 1993). Umali (1993) also cites some indirect evidence collected by the Secretararia de Agricultura y Recursos Hidraulicos of Mexico that shows that 357,000 ha in the Northwest districts and 96,000 ha in the Lerma Balsas region in Mexico that were affected in varying degree by salinity resulted in an estimated loss in agricultural productivity in these areas of about 30-50 percent in ten years. Similarly, the impacts of salinity in reducing Pakistan's agricultural output is estimated to be on the order of nearly 25 percent (Chakravorty, 1998). Unfortunately, the farm income effects of such declines in productivity are not estimated but its magnitude can be hypothesized from the above figures.

An extreme environmental consequence of soil salinity and alkalinity is that the land becomes uncultivable at high levels of salt build-ups in the soil. When this occurs, the land is abandoned, unless huge investments are made in engineering work to restore these soils. According to UNEP estimates, salinity in irrigated areas is the primary cause and overall it is the second major cause of the loss of agricultural land (Umali, 1993). However, the estimates of global loss of arable land due to salinity are difficult to find. There are some estimates available at country levels. In India, for example, an estimate suggests that 7 million hectares

have been abandoned because of excess salts (Umali, 1993). In Mexico, according to estimates by Yudelman (1989) more than 50,000 ha have been abandoned due to salinity in the late 1980s. The direct environmental consequences of abandoned land due to soil salinity problems is that it creates demand for more new land to be brought under cultivation. Thus, it negates the environmental benefits in the form of potential land-savings, which result from productivity-enhancing technologies.

There are no accurate global estimates of the damage caused by salinisation to the economy of salt-affected countries. Ghassemi *et al* (1995) provide a few examples of aggregated estimates of monetary losses suffered by an economy from irrigation-induced soil salinity. The values summarized in Table 3 for a number of countries give an indication of the severity of the negative economic impacts of salinisation. In Pakistan, for example, the economy of Punjab and the North West Frontier Provinces suffer an estimated Rs. 4.3 billion or US \$300 million annually from the decrease in farm production on soils slightly to moderately affected by salinity. Similarly, in the Republic of South Africa the annual economic damage for the communities of Pretoria, Witwatersrand, Vereeniging and Sasolburg complex due to an increase of salt content in the Vaal Barrage was estimated to be US \$29 million per year. In the United States and Australia, the costs of agricultural losses and damages to natural resources are estimated in millions of dollars in specific parts of the country (Table 3). The loss at a national scale in all these countries would be much higher than reported in Table 3.

On the global scale, Dregne *et al* (1991) estimated that the loss in production capacity, or what they call "income foregone", due to all processes of land degradation is about US\$ 42.2 billion in 1990 prices (Table 4). The estimate of 45.4 M ha of salt-affected lands in irrigated areas and the income loss values per unit area for irrigated lands given in Table 4 can be used to infer the global income loss due to salt affected lands. Based on these figures and assumptions, Ghassemi *et al* (1995) estimate the global income loss due to irrigation induced salinity to be US \$11.4 billion. Taking into account damages caused to industrial users of saline water and to water distribution systems, Ghassemi *et al* (1995) contend that the total damage may exceed US\$ 15 billion per year.

In conclusion, there has been a fair amount of empirical evidence and global estimates of the extent of soil salinity problems induced by irrigation. The question that obviously arises is: Is it possible to derive aggregate estimates (even a ball-park estimate) of the environmental impacts of soil salinity and waterlogging problems based on the examples and evidence found in the literature? Some studies (given in Table 4) have attempted to measure the environmental costs of productivity loss resulting from soil salinity problems at a country- or project area-level in terms of monetary costs (loss of income opportunity). However, the conceptual and measurement issues in estimating the monetary values are too complicated to derive any meaningful estimates of aggregate environmental costs at a global level.

The potential environmental impacts of the loss of productivity are conceptually the opposite of those resulting from productivity increments. If the potential positive impact of increased productivity is "land-savings" and all the environmental benefits resulting from these savings, then the potential negative impact of decreased productivity is the use of more land to produce the same amount of output (we refer to this phenomenon as "land-use augmentation" or reduced "land-savings") and all the environmental costs resulting from more extensification.

Table 4: Estimates of damage to the economy from secondary salinity problems, a few country examples

Country	Region	Estimated damage (million US \$ per year)	Reference
Pakistan	Punjab and North-West Frontier Provinces	300 ^a	Water and Power Development Authority (1988)
Australia	Murray-Darling Basin	208 ^a	Murray-Darling Basin Ministerial Council (1989)
	Murray-Darling Basin	52 ^b	Simmons et al (1991)
	South-west of Western Australia	50 ^a	Western Australian Legislative Assembly (1991)
	South-west of Western Australia	72 ^c	Western Australian Legislative Assembly (1991)
United States	Colorado River Basin	750 ^d	Colorado River Basin Salinity Control Forum (1993)
South Africa	San Joaquin Valley, California	31 ^a	El-Ashry et al. (1985)
	Pretoria, Witwatersrand, Vereeniging and Sasolburg complex	29 ^d	Heynike (1981)

Source: Ghassemi, Jakeman and Nix (1995), Table 19.

^a agricultural loss; ^b damage from deteriorating quality of water supplies; ^c damage from waterlogging; ^d Total damage

The estimates and calculations discussed in Box 1 gives an idea of the global magnitude of the externality problems associated with irrigation-induced soil salinity measured as the potential impacts of reduced crop yields on the land-use variable. The Table in Box 1 presents some “back of the envelope” calculations of the total reduction in “land savings” (or augmentation in land-use) due to the irrigation-induced soil salinity problems in developing countries. The method used in calculating this negative environmental consequence is parallel to the “land-savings” generated as a result of yield-increasing technologies (Nelson and Maredia, 1999).

Impacts of monocropping and intensification on soil fertility

There are no reliable estimates of the extent of the intensification-induced (other than irrigation-induced) soil fertility losses around the world. The GLASOD study provides global estimates of different types of human-induced soil degradation. According to this study globally a total of 239 M ha suffer from chemical soil degradation (Oldeman *et al*, 1991). Out of these 135 M ha suffer from soil degradation due to loss of soil nutrients, 76 M ha due to salinization, 22 M ha due to chemical pollution and 6 M ha due to acidification (Oldeman *et al*, 1991). These estimates give a rough idea about the extent of chemical-related soil degradation problem existing worldwide. However, it is not clear how much of the degradation due to loss of soil nutrients, chemical pollution and acidification is a result of monoculture and intensification.

The environmental impacts of the loss of fertility due to monoculture and intensification are the reduction in yields and loss of arable land. Empirical evidence of these impacts are not well documented in the literature. According to FAO estimate, arable land is continuously going out of production at approximately 5 to 7 million ha per year (approximately 0.5 percent of total arable land) due to soil degradation. However, how much of this loss in arable land is due to intensification and monoculture is not clear.

There is increasing evidence of environmental impacts of crop monoculture and intensification in the form of declining partial and total factor productivity. Many studies report evidence of declining rates of growth in crop yields in intensively cultivated regions of South and Southeast Asia based on panel data (Pingali and Rosegrant, 1998; Pingali *et al*, 1990; Pingali, 1992; Cassman and Pingali, 1993). Similar declining productivity trends for the rice-wheat zone are also reported by Yadav (1998), Sidhu and Byerlee (1992), Kumar and Mruthyunjaya (1992) and Morris and Hobbs (1996).

There is also evidence of declining yields and factor productivity --an indicator of reduced soil quality-- based on the results from long-term experiments. Flinn and DeDatta (1984) recorded a yield decline of 30-40 percent at several sites even when nutrient input levels used to achieve maximum yields was held constant. Pingali (1992) reports evidence of declining rates of growth in rice yields in four intensively cultivated “rice-bowl” regions of Southeast Asia. The magnitude of yields foregone due to declining soil nitrogen supply as a result of continuous (two to three crops per year) flooded rice cultivation systems are estimated by Cassman and Pingali (1993). Using long-term experiment data from the IRRI farm, the authors relate the long-term yield decline to changes in soil nutrient status. They estimate the decline in yields to be around 30 percent over a 20-year period, at all nitrogen levels. Recent estimates by Dawe *et al* (2000) showed statistically significant yield declines in three out of four long-term field trials of IRRI farms. However, data on yield trends in 30 long-term experiments conducted at 24 sites (both at IRRI and outside) with intensive rice monoculture

Box 1. Estimates of negative environmental consequences and land-use implications of irrigation-induced soil salinity problems in developing countries

The Table below presents some “back of the envelope” calculations of the total reduction in “land savings” (or augmentation in land-use) due to the irrigation-induced soil salinity problems in developing countries. The method used in calculating this negative environmental consequence is parallel to the “land-savings” generated as a result of yield-increasing technologies (Nelson and Maredia 1999). According to this calculation, the salinity problem due to irrigation has resulted in a reduction in “land savings” of about 20 million hectares in developing countries in the late 1990s. In other words, the cropping area required to produce the same amount of output as produced on the existing irrigated land with either ‘light’ or ‘moderate’ salinity problems and abandoned due to ‘strong’ and ‘extreme’ salinity degradation would be 20 million hectares less than the cropping area in the late 1990s. Of course, this estimate is sensitive to the assumptions about the yield loss impacts of salinity, which can be a source of criticism of these calculations. For example, the estimate of 20 M ha as reduced “land savings” is based on the assumption of 20% yield loss in ‘light’ salinity area, 50% yield loss in ‘moderate’ salinity area, and 100% yield losses in the ‘strong’ and ‘extreme’ salinity degraded areas. Lowering the values of these yield loss parameters by 10% points will lower the estimate of “land savings” by 15%. Moreover no considerations are made for the cropping intensity of the degraded lands and its implications on yield loss per unit of (gross) area cultivated. Since, most irrigated lands grow 2 or more crops per year, and assuming that saline soils negatively affect yields of all the crops grown on a given land (although at different rates), the estimate of 20 M ha as reduced “land savings” may be an underestimation of the potential externality costs.

POTENTIAL AREA IMPACTED BY EXTERNALITY

A. Total irrigated area –1998 (1000 ha) ^a	205,000
B. Estimated area with salinity problem (1000 ha) ^b	
1. Light	20,000
2. Moderate	10,000
3. Strong	11,500
4. Extreme	200
TOTAL	41,700

NEGATIVE ENVIRONMENTAL CONSEQUENCES

C. Land abandoned due to salinity (1000 ha) (strong + extreme degradation) ^c	11,700
D. Decrease in yields due to salinity ^d	20-50%

LAND USE IMPLICATIONS ^e

E. Area needed to produce the same amount of production if “light” and “moderate” salinity problem did not exist (1000 ha)	21,000
F. Area that could have been saved if “light” and “moderate” salinity problem did not exist (1000 ha) (difference between problem area and the area needed to produce the same amount of output)	9,000

Total land savings avoided due to salinity (late 1990s) (1000 ha) ^f

20,700

a. FAO online database

b. Oldeman *et al* (1991) estimate the global extent of human-induced salinization that has resulted in light, moderate, strong and extreme degradation to be about 35, 21, 20, and 0.8 M ha respectively. Out of this about 5 M Ha are in Europe, Australia and North America. Adjusting the remaining land area estimates in each category for irrigation-induced soil salinity problems (which is 60% of the total salt-affected area based on Ghassemi *et al* (1995, p. 42) calculations, we derive the figure of 20, 10, 11.5 and 0.2 M ha as an educated guess for total area affected by different degrees of salinity degradation in irrigated areas of developing world.

Box 1 (cont'd)

- c. The figures for India and Mexico based on studies cited in the paper estimate 7 M ha and 0.5 M ha, respectively as land abandoned due to salinity. But no global estimates on land abandoned due to salinity are available. We assume the last two categories of degradation unsuitable for cultivation and therefore a close estimate of "land abandoned".
- d. An average 20% yield loss for "light" degradation and 50% yield loss for "moderate" degradation is an educated guess of the authors based on the various empirical evidence discussed in the text.
- e. Calculated by the Panel members based on above estimates
- f. Sum of C and F.

or rice-upland crop systems in tropical and subtropical regions of Asia suggest that while yield declines exist in some long-term experiments, they are less common than previously thought, particularly at moderate yield levels. Where yield declines did occur, they were related to soil properties affected by prolonged soil wetness or soil nutrient depletion (Dawe *et al*, 2000).

The long-term experiment station yield trials conducted in Pantnagar, India also show yields declined 0.5 percent per year for wheat and 2.8 percent per year for rice (Nambiar, 1994). The long-term fertilizer experiment yield trials conducted on the rice-wheat system at four locations in India showed that the overall mean yields for all locations declined for rice over the 16-year period in all treatments and for wheat declined only in the control treatment (no fertilizer applied) (Yadav, 1998). Most of the evidence on the long-term yield impacts of crop monoculture found in the literature are based on experiment station trials. With the exception of a few studies, there is not much evidence and empirical estimates of farm-level yield impacts of crop monoculture.

Conceptually, the reduced "land savings" as a measure of environmental impacts of irrigation-induced land degradation discussed in Box 1 can be estimated for soil fertility problems that result from monoculture and intensification. However, there are no global estimates on the extent of soil fertility problems associated specifically with monoculture, fertilizers and pesticides to derive an aggregated estimate of the externality effects on land-use augmentation. The only guide to estimate a ball-park figure is the estimates by Oldeman *et al* (1991) on the extent of global human-induced soil degradation discussed earlier in Section 3.1. According to these estimates soil degradation due to loss of nutrients, pollution and acidification is 163 M ha globally. Out of this, about 58 M ha are lightly degraded, 83 M ha are moderately degraded, and 22 M ha are strongly degraded. Following the same reasoning and assumptions about yield losses due to the loss of soil fertility under these different categories of degradation as with salinity problem, the ball-park estimate on the global reduction in land savings due to soil fertility losses (other than salinity) is roughly 76 M ha globally. Note that unlike the salinity land loss estimate, this estimate is global (i.e., includes both industrialized and developing worlds).

3.2 Food and Water Contamination and Exposure to Toxic Chemicals: Human Health Impacts of Chemical Inputs

Chemical inputs used to increase agricultural productivity, such as inorganic fertilizers and pesticides have been associated with many negative direct and indirect human health impacts.

Pesticides as such are toxic chemicals and represent risks to users. In developing countries, where users are often illiterate, ill-trained, and do not possess appropriate protective equipment, the risks are magnified. Furthermore, comprehensive bodies of legislation to regulate the use and distribution of pesticides often do not yet exist. It is estimated that only 0.1 percent of applied pesticides reach the target pests, leaving the bulk of the pesticides (99.9 percent) to impact the environment (Pimental, 1995). Human pesticide poisonings and illnesses are clearly the largest “environmental costs” paid by a society for pesticide use.

There is a fair amount of empirical evidence that links pesticides on a case-by-case basis with human deaths as a result of poisoning, deterioration in human health with long-term exposure to toxic chemicals (e.g. studies reported in Forget *et al*, 1993), and indirectly reducing the diversity in nutritional sources of food by poisoning or contaminating complementary food sources in the fields treated with pesticides (e.g. fish in a paddy field) (Pingali and Roger, 1995).¹ However, there is very limited empirical evidence of the extent of these impacts on human health at an aggregate level. A decade ago, the World Health Organization (WHO) estimated worldwide pesticide poisoning cases of 3 million per year with approximately 220,000 being fatal (WHO 1990 cited in Pimental and Greiner, 1997). However, it is not clear how many of these are occupation related and how many are self-inflicted incidents (like suicides). Also, it is not clear how many of the cases can be linked with pesticide use in agriculture as against industrial and household use.

Rola and Pingali (1993) and Antle and Pingali (1994) for rice, and Antle, Cole and Crissman (1998) for potato provide a comprehensive yet site-specific evidence of linkages between pesticides used in agriculture and negative human health and other environmental consequences, and estimates of these impacts on agricultural productivity. The study by Rola and Pingali (1993) found that:

- Pesticide use has a significant positive association with the incidence of multiple health impairments in Philippine rice farmers, even after accounting for other effects (e.g. age, smoking, drinking habits and nutritional status).
- The average health cost for farmers exposed to pesticides was approximately 40 percent higher than that for the unexposed farmers. Even after accounting for other factors, health costs increase by 0.5 percent for every 1 percent increase in insecticide dose above the average level.
- Health impairment lead to a loss in labor productivity.

The value of the crop loss to pests was invariably lower than the health cost associated with pesticide exposure. When health costs were accounted for, the natural control (“do nothing”) option was the most profitable and useful strategy for pest control. When farmers applied the recommended two doses of insecticides, net profits increased by Philippine Pesos (PHP) 277 compared with a farmer who applied only one; however, health costs went up by PHP 330, resulting in a net loss of PHP 53.

Thus the Philippine rice study indicated that farmers’ health had a significant impact on the productivity of Philippine rice farms, and that pesticide use in rice production had a

¹ Pimental and Kahn (1997) present an interesting argument that serves as a food for thought for impact assessment. They argue that these negative externalities mainly associated with cosmetic pest control “sharply contrasts to no known cases of human poisoning or death from ingesting insects or mites in or on food.” (p. 417).

significant impact on farmers' health. A simulation analysis showed that restricting the use of pesticides that posed the greatest health risk was a "win-win" policy, as it would increase both the health and productivity of Philippine rice farmers. Findings by Antle, Cole and Crissman (1998) of a study done for Ecuador potato farmers were remarkably similar to those of the Philippine study by Antle and Pingali (1994). However, because of the higher productivity of pesticides in the case of potatoes in Ecuador, the simulation of policy changes that reduces the use of all pesticides (both fungicides and insecticides) resulted in a tradeoff between health and farm productivity.

In addition to pesticides, leaching of fertilizer from agricultural land is also linked to ground water pollution, especially nitrate pollution with significant impacts on human health. It has been reported that drinking water containing more than 10 ppm nitrate-nitrogen causes "blue baby" syndrome in infants and stomach cancer in adults (McDonald and Kay 1988). A study conducted by Gumtang *et al* (1999) in the intensive rice cropping systems in Ilocos Norte region of Philippines found that the use of nitrogen fertilizer had resulted in well water contamination such that the nitrate-nitrogen in 8 out of 19 wells in the study area were close to or exceeded the WHO recommended limit for drinking water. High nitrogen fertilizer input increased the mean nitrate-nitrogen in ground water. However, the nitrate levels in ground water was associated with the farm management practices of dry season crop—sweet peppers. The mean nitrate level declined as the percentage of service area under rice increased. This was related to de-nitrification process in the flooded fields and the lower levels of nitrogen fertilizer for rice compared with other crops.

Empirical evidence and estimates of health and productivity impacts of pesticides and fertilizers in other crops and developing regions are very limited. In the US, some studies have tried to estimate the total costs of pesticide pollution on the environment and human health. Pimental and Greiner (1997) have estimated the total cost of damage due to pesticides in the US to be more than US\$ 8.3 billion annually. These costs include loss because of human pesticide poisoning, livestock poisoning, reduced natural enemies and pesticide resistance, honeybee poisoning, losses of crops and trees, fishery and wildlife losses, and government pesticide pollution control. If the yearly cost of US\$ 5 billion per year for pesticide treatments are added to these estimated costs of US\$ 8.3 billion, the total cost of using pesticides in the US rises to about \$13.3 billion per year. Thus, based on the estimated savings in crops of \$20 billion per year by pesticide use, the crop value per dollar invested in pesticidal control in the US would be about \$1.50 (Pimental *et al*, 1991). Thus, based on a strictly cost-benefit analysis, the benefits of pesticide use are financially positive. However, Pimental and Kahn (1997) argue that a much higher return could be realized through the implementation of non-chemical alternatives for pest control. They estimate a return to US farmers on average of about \$30 per dollar invested in pest control using non-chemical approaches such as crop rotations, biological control and breeding for host plant resistance.

Pimental (1997) contends that in contrast to the US, the negative impacts of pesticides on public health and the environment in developing countries would be great, and conceivably could reach about \$100 billion per year. The main reason is the lax regulations in developing countries on the use of pesticides both in the field and during storage.

The main conclusion of the review is that the literature is replete with empirical evidence of negative impacts of pesticides on health. However, the aggregate impacts of chemical inputs in terms of direct damage to human health and indirect effects on labor productivity are difficult to assess. The available estimates and data on human health damage assessment are

limited and very case-specific to derive even some preliminary estimates of the environmental impacts at an aggregate scale.

3.3 Environmental Impacts Associated with the Loss of Genetic Diversity

The major concerns raised against modern HYVs is that they have resulted in a **loss of diversity** of food plants often leading to the extinction of local plant races with valuable genetic resources, and the high yields have been obtained by the deliberate **narrowing of the genetic base** of these species.

The evidence of the spread and adoption of modern varieties of wheat, rice and maize, the three most important crops in developing countries affected by improved genetic technologies, gives an indication of the extent of crop area in developing countries most vulnerable to these concerns raised in the literature (Table 5). Roughly 80 percent of the wheat area in the developing world are sown to semidwarf varieties. The remainder 20 percent is split almost equally between improved tall varieties and landraces, or varieties with unknown ancestry. Similarly, about three-quarters of the rice area in Asia are planted to improved semi-dwarf varieties. In sub-Saharan Africa, landraces are still planted to a greater proportion of rice area than modern varieties, while in Latin America they occupy a very small niche. Data for maize indicate a much lower proportion of the maize area in the developing world is planted to modern types (Table 5). For sub-Saharan Africa and Latin America as a whole, roughly half of the maize area is planted to landraces, but they dominate in Mexico and Central America.

So what are the evidence of the “loss of diversity” and “narrowing of the genetic base” resulting from the adoption of productivity enhancing technologies such as HYVs. Smale (2000) provides several examples and arguments to show that these concerns are not sustained based on empirical evidence.

- First, Smale (2000) points out that evidence from a number of studies does not support the pessimistic view that the genetic base of modern varieties is restricted and tends to narrow with the introduction of HYVs. For example, nearly 90 percent of the modern wheat varieties grown in farmers’ fields in 1997 (excluding China) are CIMMYT-related. However, CIMMYT-relatedness, argues Smale (2000), “...does not imply uniformity, since these lines are a vast array of germplasm constituted by genetic recombination of different sources of materials from throughout the wheat growing world. Genealogical analysis shows: (1) a significant positive trend in the number of distinct landrace ancestors in the pedigrees of over one thousand varieties of spring bread wheat released by national agricultural research systems in the developing world since 1966; and (2) a significantly higher number of different landrace ancestors among releases that are CIMMYT-related vs. those with no known CIMMYT ancestry.”
- Second, numbers of landraces grown in farmers’ fields in and of themselves do not constitute diversity since their genetic contribution is likely to be small. In modern breeding programs landraces are typically distant ancestors. The numbers of new lines and improved materials developed by the CGIAR centers demonstrate that germplasm with different genetic backgrounds (including land races) is continually brought into the crossing blocks through an international research system. Though the numbers are smaller for rice than for wheat, Gollin and Evenson’s findings (1998) demonstrate a similar breadth of genetic backgrounds. The genetic diversity in improved lines developed by

Table 5: Adoption of Modern HYVs of Wheat, Rice and Maize as Percentage of Total Cropped Area in Developing Countries, 1990s

Regions	Wheat		Rice		Maize	
	Semidwarf and improved tall HYVs	Landraces	Semidwarf and improved other HYVs	Landraces	Hybrids and improved OPVs	Landraces
Sub Saharan Africa ^a	80	20	40	60	46	54
West Asia/North Africa	76	24	11	NA	29	71
Asia	94	6	86	14	77	23
Latin America	99	1	95	5	48	52
All developing countries	89	11	71	NA	60	40
Industrialized countries	100	(trace)	78	NA	100	(trace)

Source: Smale (2000), Table 1.

^a Figures for rice in Sub-Saharan Africa are West Africa only.

CGIAR centers represents a lower bound on the diversity of the crop germplasm currently available in national programs since national breeders cross them with their own material.

- Third, the cumulated scientific evidence (summarized in Smale *et al*, 2000) presents a strong case that the molecular genetic diversity and genealogical diversity of CIMMYT wheats has been maintained or has increased over the past 30 years.

What are the potential environmental impacts of the loss of genetic diversity and narrowing of genetic base and what is the evidence? The major impacts discussed and hypothesized in the literature relate to the concerns of increased vulnerability of HYVs to major pests and diseases. Since the United States corn leaf blight of 1970, public concern has focused on the potential for plant disease epidemics caused by uniformity in the genetic base of resistance. In fact a major environmental concern of modern varieties, which are believed to have a narrow genetic base, is the increasing yield variability resulting from susceptibility of crops to pest and disease epidemics.

Despite the concerns raised, there has been very little empirical work to estimate the extent of this loss due to the development and spread of HYVs, and its impact on productivity. Recently, there has been some progress towards filling this gap in the literature as some studies have attempted to measure the impacts of genetic resources and diversity on crop productivity (summarized in Smale, 1998). Preliminary results from Pakistan, China, and Australia confirm the dampening effects of older variety age on productivity, demonstrating beneficial effects of genealogical diversity on productivity and yield stability, and suggesting that marginal costs may be associated with greater evenness in the spatial distribution among modern wheat types (Smale *et al*, 1998).

The study by Hartell *et al* (1998) finds evidence of increasing genetic resource use and diversity in the Punjab of Pakistan over the brief time period of the study, as illustrated by the number of distinct landraces and parental combinations appearing in the pedigrees of wheat varieties grown in farmers' fields, as well as by indices of spatial diversity and genealogical distance. Temporal diversity declined during the study period, however. The results of this study suggest that greater genealogical distance and increased temporal diversity are associated with reduced yield variability among the districts of Punjab from 1979 to 1986. In the rainfed environment, genealogical distance and number of landraces in the genetic background of varieties were positively associated with mean yield. In the irrigated areas, only the concentration of area among fewer varieties and the age of varieties had a significant impact on yield. When more area is concentrated among fewer varieties, spatial diversity decreases and the risk of yield losses from disease increases.

On the issue of inverse relationship between genetic uniformity in crop populations and crop yield stability, Smale (2000) provides following examples to show that the claims made by critics that "the spread of modern varieties increases yield instability" has not borne statistical scrutiny. For example, the comprehensive study by Hazell (1989) found that the overwhelming sources of rising production variability in cereals over the 1960-1982 period were increases in yield variance and simultaneous loss of offsetting variations, which were more likely to have resulted from synchronization of water, fertilizer, and other purchased inputs over large areas, than from greater sensitivity of new seed types and genetic changes. In Hazell's analysis, argues Smale (1999), production variability did not increase for all crops — in particular, it declined for wheat during the years of the green revolution. Other analyses conducted later on confirmed this result for subsequent decades and different geographical scales (Pfeiffer and Braun, 1989; Sayre, Rajaram and Fischer, 1997; Singh and Byerlee,

1990; Smale, 1998). Smale (2000) also cites studies for rice and wheat (Brush, 1992) and for rice in Bangladesh (Alauddin and Tisdell, 1988) that refute the postulation that 'crop yield instability increases with the diffusion of modern varieties in the cradle areas of crop domestication and genetic diversity'.

In summary, given the limited and contradictory evidence in the literature, the impacts of loss of diversity on crop productivity and yield stability are difficult to assess. There have been no attempts made at speculating an aggregated cost of the loss of genetic diversity on the environment and human health. With the current scientific knowledge, it is not possible to state categorically whether the spread of HYVs has led to a decline in the genetic diversity and what have been their impacts on crop productivity.

4. Responses by CGIAR to Mitigate Externalities

Without doubt, some of the GR technologies set in train some of the negative environmental impacts which are manifest today – but a credible estimate of the percentage would be extremely difficult to calculate. At the same time, recognition of the actual or potential RNR degradation and its consequences for human well-being have triggered a number of remedial responses from the CGIAR-NARS research partnerships.

Over-application of pesticides and fungicides led to a quick response from the CGIAR and NARS research systems in the form of crop genetic improvement research to develop pest-resistant varieties (host plant resistance) and integrated pest management. Significant advances have been made by the CGIAR-NARS collaborative system in the last three decades in the development and dissemination of crop varieties with resistance to the major cereal pests (Table 6). Early work at IRRI reported that most of the important sources of resistance to major diseases and pests had been incorporated into modern rice varieties. For wheat and maize, CIMMYT has an active program that develops maize and wheat germplasm with desirable levels of resistance to insect pests and diseases. CIMMYT combines "shuttle breeding" and "hot spot" multi-location testing within Mexico and abroad to obtain multiple disease resistance for the different agroecological zones in environments where wheat and maize are grown. Because of these research efforts, rice, wheat and maize now has resistance to major insects and diseases important to these crops in developing countries (Table 6). Similar approaches of incorporating resistance to major pests and diseases is also taken for other food crops such as potatoes, cassava, sorghum and millet. For example, the development of effective integrated late blight management practices in potato is the top priority research problem in CIP. Durable varietal resistance is at the heart of the strategy. A team of researchers is using conventional plant breeding and molecular genetics techniques to produce populations of potato clones with the desirable characteristics (Antle *et al*, 1998).

One of the benefits of the introduction of varieties with host-plant resistance is the reduction in the need for insecticides for rice and maize and fungicides for wheat. Evidence for the three major cereals indicates that the extent of crop loss due to insects and diseases has dropped over the last two decades and that the extent of yield loss due to the failure to apply chemicals has declined significantly (Litsinger, 1991; Waibel, 1986; Pingali and Gerpacio, 1997; Sayre *et al*, 1997).

Survey evidence from Peru suggested that late blight resistance of one of the potato variety had resulted in reduced use (about 40 percent less than applied on other non-resistant HYV)

of fungicides per hectare. Farm survey evidence from Tunisian potato farmers shows the impact of IPM. In 1986, chemical insecticides were the principal means of managing potato tuber moth, with about 46 percent of farmers applying at least one treatment to their fields. By 1990, the incidence of farmers using chemical pesticides in their fields had fallen to 14 percent.

Table 6: The Evolution of Host-Plant Resistance for the Major Cereals, 1960s-90s

Period	Rice	Wheat	Maize
1960s	Striped stemborer	Stem rust	European corn borer
1970s	Brown planthopper, green leafhopper, rice whorl maggot	Septoria tritici blotch	Earworms, tropical borers, southwestern corn borer
1980s	Elbow stemborer, white-backed brown planthopper, thrips	Leaf rust	Fall armyworm
1990s	Bacillus thuringiensis	Spot blotch, fusarium scab, stripe rust	<i>Bacillus thuringiensis</i>

Source: Pingali and Gerpacio (1998), Table 19.6

The emphasis on releasing rice, wheat, maize, potato and other crop varieties with improved host-plant resistance to major diseases and pests has continued in the CGIAR since 1970s. Much of the advancement has occurred through the use of conventional breeding approaches, although substantial future gains in resistance development could come through the use of modern biotechnology tools. Another major response of the CGIAR-NARS system towards negative human health impacts of pesticides was the promotion of integrated pest management (IPM) strategy for pest control. The study by Waibel (1999) provides a good historical perspective on the activities of the CGIAR centers in the area of IPM, and provides a preliminary assessment of the benefits of this approach. Success stories of IPM by CGIAR centers include the biological control of cassava mealybug in West Africa (Norgaard, 1988), IPM practices of the Andean potato weevil in Peru, and the IPM message of “no spray for 40 days” developed by IRRI scientists and relayed to rice farmers in Asia.¹

To address the public concern on the potential for plant disease epidemics caused by uniformity in the genetic base of resistance, one of the response of CIMMYT was to use non-specific resistance as the dominant selection methodology in their wheat breeding program for the past 25 years. This strategy emphasizes the accumulation in varieties of multiple genes conferring partial, race-non-specific resistance. The implication of this strategy is that the rate of disease progress is slowed making the plant more likely to endure for many cropping seasons and reducing the probability of disease epidemics and mass-scale crop losses in any one year.

¹ This approach, reports Waibel (1999), has been tested in Vietnam and is claimed to be successful (Heong *et al.*, 1998 cited in Waibel 1999) but no formal economic analysis has been conducted.

Several of the major wheat varieties grown in the developing world today, and most of CIMMYT's bread wheat germplasm, contain in their pedigrees the ancestral source of the gene combinations for stem and leaf rust resistance that are believed to confer resistance of a durable nature. Smale and Singh (1998) provide an estimate of the benefits of CIMMYT's strategic response of adopting the non-specific resistance (rather than specific resistance) strategy in their wheat-breeding program in 1970. Expressed in 1994 real terms, the benefits generated in the Yaqui valley of Mexico from this breeding strategy were estimated to be US\$ 17 million.

Despite the efforts by the CGIAR system to mitigate the environmental problems of some of the early technologies and recommendations by taking the above-discussed steps, there were cases where CGIAR did not respond rapidly. For example, there were no remedial measures taken to address the soil salinity problem or the reduction of herbicides. The research system responded partially to the salinity problem by developing salt-tolerant varieties. But this approach does not solve the salinity problem, it only changes the slope of the crop-yield response curve to salt-affected soils making the crop cultivable to saline soils. In the case of herbicides, there are few genetic and management alternatives, and those that exist are generally not very cost-effective. The use of more competitive cereal varieties can avert the effect of weed competition and the consequent use of more herbicides, but there appears to be a tradeoff between yield and the plant's ability to compete with weeds (Moody, 1991). Research on varietal improvement for weed management in cereals is still at a very early stage (Khush, 1996). The development of genetic resistance to *Striga*, the most important weed in Africa, is an exception to the lack of success in using genetic means for controlling weeds. Among the management options for weed control that minimize labor use are the case of wheat and maize, the use of ridge tillage systems (Sayre, 1996) and the use of cover crops and intercropping. However, none of these options has proven to be economically as attractive as the use of herbicides, and the challenge for the research and policy community is to find cost-effective mechanisms for reducing herbicide use in cereal crop production.

The release of resistant varieties was a successful pro-active step by CGIAR and NARS towards addressing the environmental and health impacts of pesticides. However, these varieties were not accompanied by supporting information campaigns on the reduced need for insecticides. The recommended technologies from the initial period of the Green Revolution were for the protection of crops from pests through prophylactic application of insecticides and fungicides. So strong was that technology message that the association of modern cultivars and pesticide application remains with farmers until today, notwithstanding the current integrated pest management programs. For example, while the rice varieties IR36 and subsequent cultivars with host-plant resistance traits were grown over wide areas, they were not associated with a reduction in pesticide use. Fischer and Cordova (1998) contend that "...one of the failures of the period was the failure to communicate the 'new knowledge' in HPR, which had been incorporated in the seed, to farmers as they switched to growing the next generation of MVs. Farmers (and extension agents) maintained the old regime of pesticide application with the MVs even though the properties of the varieties had changed dramatically." Consequently, continued high and injudicious insecticide applications by farmers led to the frequent breakdown in varietal resistance, and more application of pesticides.

5. Attributing Environmental Impacts to Research: Problems and Possibilities

The ex post impact assessment of agricultural research that measure rates of return to research investments have traditionally measured impacts of research up to the productivity effects in the “research-to-impacts” chain illustrated in Figure 1 (e.g. yield effects and impacts on cost of production). The challenge for the environmental impact assessment of productivity enhancing research is to analyze and measure the effects beyond productivity effects. This means quantifying the positive and negative externalities and assessing the environmental impacts of these externality effects. To assess the environmental impacts of past research, the negative externality effects discussed above need to be deducted from the positive externality effects of productivity-enhancing research, namely the “land savings” and improved human health and nutritional status of populations (Figure 1). However, in both cases the question arises: how much of the observed consequences can be attributed to research? For example, what would have been the trend in the loss of soil fertility and genetic erosion, and human health impacts of chemical inputs without agricultural research? The answer hinges on the methodological and conceptual issues of impact assessment, namely the problem of attribution and determining the counterfactual. It depends on analysing what factors contributed to or encouraged the intensive use of productivity-enhancing technology components and determining which externalities would have occurred even without the CGIAR research and which occurred because of it.

The emerging conclusions from the review indicate the difficulty and complexity of solving these problems. There are two main reasons for this. Firstly, **factors other than technology** (i.e., technological and economic change, social and political policies) **have played an important role in creating these problems**. Secondly, **many of the problems** of negative externalities observed today and discussed in the literature **have nothing to do with new technologies** that resulted from agricultural research (such as the Green Revolution technologies in the 1960s and 1970s). The underlying causes of agricultural intensification are usually multifactorial. For example, the problems associated with intensive use of irrigation would have occurred without the use of modern varieties or other inputs. In this section we present evidence that support both these arguments.

5.1 What Factors Contributed Towards Negative Environmental Consequences?

The underlying causes of externalities discussed in the literature are usually multifactorial. Technological and economic change, social and political factors, all play a role. Each particular environmental problem listed above has its own peculiar causative factors. Pesticide problem, for example, is partly a consequence of input “misuse” or “overuse”. This has occurred for several reasons. First, the benefits relative to costs have been substantial, especially where there have been heavy subsidies either of input use or in the form of crop support prices. Subsidized or almost free availability of water supply has been an important factor in the overuse of ground and surface water for crop production (Piementel *et al*, 1997).

Rola and Pingali (1993) have argued that pesticide use has been promoted by policy makers’ misperceptions of pests and pest damage. Policy makers commonly perceive that modern variety use necessarily lead to increased pest-related crop losses and that modern variety use necessarily lead to increased pest-related crop losses and that modern cereal production is therefore not possible without high levels of chemical pest control. In addition to the

incentive to use more pesticides, subsidies also discourage traditional methods of pest control, which are usually more labor and time consuming, and they work against the uptake of alternative, and perhaps, less polluting, approaches.

Second, in the case of pesticides, farmers tend to spray in anticipation of pest infestation and loss. This is especially true of high value crops, such as fruits and vegetables, because of public demand for unblemished products. Linked to the financial incentives for input use has been the rapid spread of technologies and new practices, which come as packages of closely interlinked components. Direct seeding, for example, requires support from intensive herbicide use. In this way farmers can become locked into an intensive system of agriculture where pesticides appear to be indispensable.

Improper technology design and mismanaged technologies are also important causes of negative externalities. The soil salinity problems associated with irrigation technology, for example, have been a result of poor or no drainage system. Drainage investments were deliberately left out of irrigation projects to keep the cost down (NAS 1989). A review of fertilizers and environmental concerns concluded that "in the developing countries, the principle cause of environmental effects is unscientific fertilizer practices and not excessively high rates of application" (Rustagi and Desai, cited in Pinstup-Andersen and Pandya-Lorch, 1994, p. 15). There are also institutional causes of negative environmental consequences. For example, the soil degradation problem as a result of decline in soil fertility is triggered by the lack of property rights framework (Pingali, 1989).

5.2 *What Would Have Been the Externality Impacts of Productivity-Enhancing Technology Without CGIAR Research?*

Which externalities would have occurred despite CGIAR research on yield-enhancing technologies such as HYVs and which have occurred because of it is a matter for debate. Many of the negative externalities observed today in developing countries are environmental problems of agricultural intensification, which would have occurred despite high yielding varieties developed by the CGIAR-NARS systems in the 1960s and 1970s.

The underlying causes of agricultural intensification are usually multifactorial and many of the problems associated with intensive use of inputs would have occurred without the use of modern varieties. This is evident from the close scrutiny of the ecological consequences observed today in the state of Punjab, India (Brar, 1999). This region is perhaps the most affected by the Green Revolution technologies of the 1960s and 1970s. However, a close examination of some indicators of externalities associated with Green Revolution reveals no direct relationship between the intensity of Green Revolution and the severity of negative externalities (see Box 2).

Estimating the environmental consequences in the counterfactual situation will thus depend on determining the type of technology that would have prevailed in the absence of CGIAR research and the accompanying policy environment. In terms of attributing environmental costs to past research efforts a possible option is to consider the contribution of mainstream research as speeding the rate of increase in the intensive use of inputs such as fertilizers, pesticides and irrigation. A possible option for ex post assessment of environmental costs is therefore to construct a "without" technology scenario based on input use observations lagged by "n" number of years, where "n" is to be determined based on a careful examination of technical and policy factors for a given input on a case by case basis. Alternatively, estimates

of counterfactuals can be derived using a general equilibrium framework and modeling input use (HYVs, irrigation, fertilizers, pesticides) as functions of different technical, economic and policy variables, and relating them with an associated measure of externalities at different levels of input use.

Box 2. Assessing the environmental impacts of the Green Revolution in Punjab, India: A case example

To analyse the ecological implications of the Green Revolution in the state of Punjab, Brar (1999) constructed a Green Revolution intensity indicator for each of the 118 “development blocks” in the State. The Green Revolution intensity was defined as the area under paddy-wheat rotation as a proportion of the cropped area in a given “development block”. According to this intensity measure, the blocks were classified into four “Green Revolution intensity” groups: blocks with intensity index more than 0.75, 0.50-0.75, 0.25-0.50, and less than 0.25. Higher numbers indicate a higher intensity of Green Revolution in a given block. For example, an intensity of 0.75 means at least 75% of total cropped area in the development block is under rice-wheat rotation.

A simple cross tabulation of some of the measures and indicators of externalities associated with Green Revolution technology, namely decline in water tables, soil nitrogen deficiency, and soil salinity, with the intensity index indicate no direct relationship between the Green Revolution intensity and severity of negative externalities (Brar 1999). For example, only one-third of the blocks in high intensity (more than 0.75) region of Punjab recorded a fall in water table by more than 3 meters as against a majority of blocks in the 0.25 to 0.50 intensity blocks showed a decline in water table by more than 3 meters. This shows that local conditions of subsurface water have their own role to play in the dynamics of changing water tables. Similarly, some of the badly affected soil salinity areas were found to be in Bathinda and Faridkot districts which fall under the intensity index of less than 0.25 and 0.50, respectively.

Source: Brar (1999)

6. Conclusions

Our main objective in this paper was to bring together empirical evidence and estimates of the environmental impacts associated with productivity-enhancing CGIAR technologies so as to derive summary statements about the environmental impacts of research that we feel confident about. Several conclusions are drawn from the review of the literature related to the negative externalities associated with monoculture and the increased intensity of “external” input use — irrigated water, fertilizers, and pesticides. These are summarized below:

- The literature is replete with anecdotes and case examples of how the HYVs negatively impacted the environment and social structure and, as a result, impaired long-run human well-being. However, there is very little scientific evidence in support of some of the claims of negative externalities. Some of the claims of negative externalities that lack scientific rigor include statements such as: Green Revolution led to “genetically uniform crops”, “produced crops that are inherently more susceptible to disease”, “require increased mechanization” (Wakeford, 2000). The review of the literature suggests that

such claims made by the critics of modern agriculture are either not substantiated by data or the evidence is too scattered to enable any generalizable conclusions about their validity, at least in the context of developing country agriculture.

- In cases where the scientific evidence strongly linking a technology component with negative externality does exist (e.g. soil salinity) it is difficult to trace the link (and blame) to mainstream research. There are two main reasons for this:

Firstly, factors other than agricultural technology (other technological changes and perverse policies or institutional arrangements) have played an important role in creating these problems. For example, poor irrigation system design and management are primary factors leading to salinity problems. The pesticide problem is partly a consequence of input “misuse” or “overuse”. This has occurred for several reasons, including the subsidized or almost free availability of some inputs (e.g. water, electricity) and changes in consumer demand for cosmetic quality which induces farmers to use more pesticides. There are also institutional causes of negative environmental consequences. An example is soil degradation as a result of decline in soil fertility, triggered by the lack of property rights. In situations where these rights do not exist, management lags behind resulting in the mining of nutrients, erosion and soil degradation.

Secondly, many of the environmental problems observed today have nothing to do with new technologies that resulted from agricultural research (such as the GR technologies developed in the 1960s and 1970s). The underlying causes of agricultural intensification are usually multi-faceted. Problems associated with intensive use of irrigation would have occurred without the use of modern varieties or other inputs. For example where the traditional Basmati rice variety is grown in India and Pakistan has one of the world’s worst salinity problems. Similarly, some contend that the practice of monoculture would have gained popularity even in the absence of the GR. Thus, it is difficult to show that in the counterfactual situation of “without research” the world would be free of many of the negative externalities that exist today.

- The evidence of negative externalities of intensive input use in developing countries is limited to GR crops — wheat and rice, and to a limited extent to maize. There are many other CGIAR mandated crops (e.g. potatoes, beans, roots and tubers) that are important in developing countries (and for which improved technologies have been developed and adopted by farmers) but for these crops little evidence has been presented on negative externalities. This either reflects the fact that negative externalities associated with input intensification are limited to wheat and rice or that there is a need for more studies documenting the externality impacts in other crops in developing countries. Because of the bias in the documentation of externality problems towards wheat and rice, it is difficult to separate the negative impacts associated with the GR, which was a product of the mainstream agricultural research (spearheaded by the CGIAR) from the impacts of agricultural intensification, which is caused by factors other than research. The confusion between these two phenomena (GR and intensification) has led to misconceptions linking environmental degradation with agricultural research.
- Whether the cause is technological change, government policy, or institutional framework, the pressures for greater input use to increase productivity have certainly increased the hazards to the environment. Even though it is difficult to establish a link between the negative externalities and agricultural research, the evidence found in the literature provide a powerful message that agricultural research needs to be sensitive to

the results of new technology, and that EIA should be incorporated in overall research impact evaluation to provide a more balanced view of the environmental costs and benefits.

- In summary, without doubt some of the early Green Revolution technologies set in train some of the negative environmental impacts which are manifested today – but a credible estimate of the percentage would be extremely difficult to calculate. At the same time, recognition of the actual or potential natural resource degradation and its consequences for human well-being have triggered a number of remedial responses. Over-application of pesticides and fungicides led to crop genetic improvement research to develop pest-resistant varieties and integrated pest management. Although fertilizer use increased because of the advent of HYVs, the varieties became more efficient in the uptake of nutrients, thus reducing fertilizer input per unit of output. HYVs favored expansion of irrigation, sometimes onto unsuitable areas, or onto areas requiring a standard of water management that was not available. The attribution of environmental damage to HYVs in such cases is clearly questionable. Nevertheless, these consequences generated a response in the form of additional research on water management (creation of IIMI) and development of varieties which were resistant to salinity and more efficient in use of water. The charge that HYVs have reduced biodiversity is difficult to sustain. The countless crosses that have been made by NARs and the private sector could be said to have increased genetic diversity. In addition, the System (and others) have responded by setting up genebanks and establishing the IPGRI.

In the end, we do not pretend that this paper is a complete and comprehensive review of the technology-induced environmental problems in developing countries. A more comprehensive description and analysis of the problem would require a series of case studies, each describing all aspects of the problem within a country or eco-region within a country. A preliminary framework of what these case studies should be is given in Annex 1. Given the pressure on the CGIAR to demonstrate impacts of research in an unbiased and objective manner, we recommend that SPIA should take the initiative and leadership in implementing these case studies. These case studies will hopefully fill in the gap in the literature on the environmental impacts of modern technologies and help clarify the myths and realities of the impact of research on the environment and human health.

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Environmental Impact Assessment of CGIAR Crop Technologies A Preliminary Framework for Case Studies

1. Rationale and objectives

The review of the literature on the negative externalities of agricultural research points to the lack of empirical evidence on the impacts of research and modern crop technologies on environment and human health. There have been several studies that point to the linkages between increased input use and negative externalities of the crop technologies on the environment and human health. But there is not much empirical evidence on the environmental impacts of these externalities in the form of productivity effects on agriculture itself.

The purpose of proposed case studies is to review the linkages between environmental degradation and crop technologies in specific regions of the developing world which are most impacted from CGIAR research. The objective of these case studies is not to deal with the question of *what went wrong*, but to provide a more balanced view of the environmental impacts, which have resulted from the introduction of CGIAR-NARS technologies and which need to be accounted for in assessing the environmental costs and benefits of past research efforts. More specifically, the objectives of these case studies will be:

1. To identify and assess the extent/magnitude of externality problems associated with past CGIAR/NARS research in a specific geographic region;
2. To estimate environmental, human health and economic impacts of these externalities;
3. To analyse the conditioning factors (policies, institutions) that contribute towards the negative environmental consequences; and
4. To provide a preliminary analysis of problems and possibilities of deriving aggregated estimates of environmental costs and benefits of CGIAR/NARS research.

2. Possible candidates for case studies

One of the conclusions of the literature review is that there is very limited evidence of negative environmental impacts in crops other than rice and wheat. To address this concern for the lack of evidence on other CGIAR mandated crops, we propose the following crops/regions as possible candidates of further case study research:

Crop	Region	CG-Center
Wheat-Rice	Punjab, India	CIMMYT
Wheat	Yaqui valley, Mexico	CIMMYT
Rice	Central Luzon, Philippines	IRRI
Maize	Western Kenya	CIMMYT
Sorghum, Millet, Pulses	Andhra Pradesh, India	ICRISAT
Potato	Ecuador	CIP
Cassava	Nigeria	IITA
Barley, Chickpeas	A country from WANA	ICARDA
Beans	A country from LA region	CIAT

3. Methodology

Each case study will address the following questions/issues for a given crop(s) and area of study.

- a. Identify major environmental issues:
 - identify major environmental issues associated with improved crop technologies
- b. For each of these environmental issues:
 - identify positive and negative externalities based on empirical studies in the region
 - collect data, empirical evidence, examples that establish or refute the linkage between a given technology and an externality
 - collect data, empirical evidence on the environmental and health impacts of these externalities on farm productivity
 - examine the policy and institutional framework that may have contributed to generating the externalities
- c. Assess/estimate environmental impacts of crop technologies in a given geographic study area:
 - estimate impacts on crop productivity, yield variability, loss of income opportunities, etc.
 - derive relationships between technology components and environmental impacts (e.g. X amount of input use increases health costs by Y or decreases crop productivity by Z; Q amount of input results in environmental costs of \$G/ha or \$K/person in agriculture) that are at least generalizable for a given crop and region
- d. Assess/estimate/explain the contribution of research in generating these impacts.

4. Expected outputs

The final output will be a compendium of environmental impacts of agricultural research that will include: individual chapters on each case study and a summary chapter that draws upon the results of all the case studies and attempts to make generalizable conclusions about the positive and negative environmental impacts of research at least for the developing regions of the world.

