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The Potential for Worldwide Crop Production Increase Due to Adoption of Pesticides

Rice, Wheat & Maize

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Executive Summary

This report estimates the increase in worldwide production of rice, wheat and maize that would result from a universal adoption of pesticides to control weeds, insects, and disease pathogens. The starting point for the study is a set of regional estimates by Oerke of the potential losses to pests for maize, rice and wheat assuming no control. Next, a simulation is made of the crop losses that would occur following universal adoption of pesticides for each crop, region and pest category. This simulation is based on estimates of the control efficacies of pesticides for each crop, region and pest category. An example of this calculation: a region has a potential yield loss of 50% and there is a pesticide option that would reduce the pest damage by 90%. Thus, the yield loss remaining following universal adoption of the pesticide would be 5%.Oerke has also made estimates of the actual crop losses that are occurring today based on an assessment of the extent and effectiveness of currently-applied controls. These actual crop loss estimates are compared to the simulated loss estimates assuming universal adoption of pesticides to determine the decrease in current losses that would occur with universal pesticide adoption. Thus, in the example, the current losses could be 12% which means that the reduction in losses from full adoption would be 7%. The gain in production as a result of full adoption is equal to the reduction in losses. Thus, the region is estimated to gain 7% in production as a result of reducing losses from 12% to 5%.

Application of this methodology suggests that worldwide universal adoption of pesticides for controlling weeds, insects, and disease pathogens would result in production gains as follows:

- Rice 26% (172 million tons)
- Wheat 18% (117 million tons)
- Maize 18% (145 million tons)

RICE

A considerable amount of research has been undertaken to estimate current rice production losses due to pests. One recent Study estimated that between 120 and 200 million tons of grain yield are lost yearly to pests (insects/diseases/weeds) in rice fields in tropical Asia [1]. The mean region-wide yield loss was estimated at 37.2% [2]. Yield losses were estimated for individual pests and were combined into one mean profile which was less than additive due to synergies between the individual pests. In this Study weeds were the first and main constraint (Table 1) [2].

A recent IRRI evaluation was that diseases cause 15% rice grain yield reductions under the current contexts of both crop production and disease management [3]. In China, sheath blight is estimated to cause a yield loss of 6 million tons of rice per year [22].

A recent Report from Africa estimates that 2.3 million tons of rice are lost annually due to weed infestations (15% of total production) [8]. In India annual losses of rice due to weeds have been estimated at 15 million tons[13].

Recent estimates for China are that approximately 10 million tons of rice are lost to weeds (5% of total production) while 6 million tons are lost due to sheath blight (3%) [4][5]. In a Study of a rice production zone of the Yunnan plateau, researchers estimated current yield losses at 13% based on an evaluation of 11 separate injuries caused by insects, diseases, and weeds (Table 2) [6]. The researchers note that their estimate is well below the commonly cited estimate of 37.2% and attribute much of the discrepancy to weeds noting that weeds are controlled to a large extent with herbicides and handweeding [6].

Worldwide estimates of actual rice crop production losses in 2001-2003 were estimated at 10.2% for weeds, 15.1% for "animal" pests (mostly insects), 10.8% for pathogens and 1.4% for viruses [7]. Total actual rice production loss for the world due to pests was estimated at 37.4% [7]. Table 3 displays the 2001-03 loss estimates by region [12].

The loss estimates for 2001-03 are lower than previous estimates for 1988-90 which totaled at 52% of total worldwide rice production lost to pests (Table 4) [7][9]. The reductions in estimated losses were the result of new information (cited above) [1]. A major factor in the downward revision was the significant increase in the use of pesticides in rice fields in Asia and Latin America [10]. Research has shown a significant and positive link between herbicide, insecticide and fungicide use and higher yields of rice [11].

Estimates have been made of the potential yield losses in rice production by region if no measures are used to manage pests [12]. These estimates are shown in Table 5.The potential worldwide loss in rice production from uncontrolled pests totals 77.03% which implies that current control measures prevent 51% of the potential loss from occurring (Table 3/Table 5). Reductions in potential losses are highest in regions like East Asia (76% to 26%) where control measures have been widely adopted and lowest in regions like West Africa (79% to 51%) where they have not been widely adopted. Current control measures include a combination of chemical and non-chemical techniques. For example, worldwide potential rice yield loss to weeds (37%) (Table 5) have been reduced to 9% (Table 3) through the use of herbicides and handweeding.

The potential for a complete adoption of chemical controls to further reduce yield losses due to pests depends on the efficacy of the chemical control products against the major pest species in the region.

Chemical control efficacy estimates for each region have been collected from the literature for pathogens, insects and weeds and are shown in Table 6. Table 6 only includes regions where at least one country has more than 500,000 hectares of rice. Table 7 identifies the countries assigned to each region.

Tables 8, 9 and 10 contain estimates of the potential gain in rice production from the full adoption of chemical controls to manage pathogens, insects and weeds respectively. These estimates are calculated by first estimating the amount of loss in production that would occur even with full adoption. These estimates are calculated by multiplying the estimates of the potential losses assuming no control by the estimates of 100 minus control efficacy. Next, the estimate of loss amount remaining with full control is subtracted from the estimate of current losses to calculate the amount that would be gained with adoption.

By summing across all regions and the three pest categories (pathogens, insects, weeds) an estimate is made of the total potential yield gain from adoption of chemical controls of rice pests: (Table 11): 198.7 million tons for a 30% increase in global rice production.

WHEAT

Prior to participation in the International Symposium on Increasing Wheat Yield Potential in 2006, participants from 19 developing countries were surveyed to identify the main constraints to wheat production in their countries [33]. These countries account for 47% of the global wheat area and 89% of the wheat in developing countries. Estimated yield loss caused by weeds varies between 8.5 and 23.9% depending on the region, and overall could cause up to 24 million tons in losses annually. Yield loss caused by diseases varies between 14 and 27% depending on the region and, overall, can cause annual losses of up to 22 million tons. The most serious diseases cited were the leaf and stripe rusts, Fusarium head blight, Septoria blotch, powdery mildew, spot blotch, and eyespot. Estimated yield loss caused by pests (especially insect pests) varies between 12.2 and 22% and can cause up to 20 million tons of loss annually. The most often mentioned insect pests include aphids, sunn pest, Hessian fly, and weevils.

In 1997 it was estimated that the adoption of crop protection pesticides for controlling weeds, diseases and insects on wheat would increase Kazakhstan's wheat yield by an average of 0.15t/ha or 23% on average [42]. In the Ukraine in 1997, it was estimated that 13.6 million tons of wheat (27%) were lost due to weeds, insects and diseases: insects (8%), weeds (10.5%), and diseases (8.5%) [43].

Resistance to rust was successfully incorporated into wheat in the 1950s in Norman Borlaug's breeding programs. The planting of rust-resistant varieties has been the recommended practice for managing rust of wheat. However, host resistance genes are often overcome by the pathogen. New races capable of overcoming single-gene conferred resistance often render corresponding resistance genes ineffective within five years. In recent years, resistance to wheat stripe rust in more than 95% of Chinese cultivars has been overcome [29]. The frequent failure of resistant wheat varieties has led to interest in fungicide control of rusts. In China, epidemics of stripe rust in 1950, 1964, 1990, and 2002 resulted in losses of 6.0, 3.2, 1.8, and 1.3 MT respectively [30]. In 2009, the early occurrence of stripe rust posed the greatest threat in many years. Timely application of fungicides effectively prevented yield losses and further spread to the wheat production regions further east. Thus, a huge yield loss nationwide was avoided through the use of fungicides [30]. In China about 6 million wheat hectares are treated with fungicides.

In India breakdown in wheat resistance to yellow rust occurred in 2008-2009 and heavy losses due to rust epidemics were reported [31]. To avoid losses in 2009-10 intensive monitoring of the rust populations were carried out. The disease was managed by the timely application of fungicides and the disease did not become widespread in 2009-10 [31]. Research in India has shown that fungicides for leaf rust and yellow rust provide disease control of 98.5% and 95.1% respectively with corresponding 65.7% and 52% increase in yield [32].

In Argentina and Brazil, over 50% of the wheat area is planted to rust-susceptible varieties because they have a greater yield potential of 20-25% than rust-resistant varieties [37]. Farmers are able to grow high-yielding susceptible varieties by using fungicides. In recent years, fungicides have been used on 25% of the Argentine wheat area and on 2.3 million wheat hectares in Brazil [37]. Research in Brazil has shown that controlling foliar diseases (powdery mildew, leaf rusts, and the leaf spot complex) with fungicides produces an increase in wheat yield of 39.8% [38].

Resistance to stem rust in most breeding programs was through the use of a single resistance gene, Sr31. In 1999, a new strain (UG99) was detected in Uganda on a wheat variety containing the Sr31 gene. Yield losses of up to 80% were reported. All the current commercial wheat cultivars in East Africa are susceptible to the new race and it is not possible to grow a profitable crop of wheat without the application of fungicides [39]. Fungicide tests in Kenya showed 50% higher yield in the treated versus the untreated plots [39]. Large-scale wheat growers in Ethiopia are reported to spend around US$0.5 million annually on fungicides [40].

Powdery mildew has spread to all parts of China since the 1980s. In India, powdery mildew is widespread on wheat in the Punjab with losses of grain yield of 20% in highly infected crop [34]. Since none of the recommended varieties is resistant to the disease, the use of fungicides has been recommended [35]. Research in India has shown an 18% increase in wheat yield following two fungicide sprays for control of powdery mildew [34].

Fusarium head blight (FHB) not only results in 5 to 15% grain yield loss in years of moderate epidemics and up to 40% in years of severe epidemics, but also causes a decrease in grain quality because of the production of mycotoxins [36]. Application of fungicide for managing FHB has been relied upon in China over the last few decades because few cultivars with effective genetic resistance are available [36].

In Australia, foliar fungicide spraying has increased due to the breakdown of resistance to stripe rust in wheat varieties. Thirty-nine percent of wheat acres are sprayed in Australia, reducing losses from yellow rust by AUS$359 million annually [41].

In 2000, wheat yield loss in China due to weed infestations was estimated at 15% of total production (4%) [4]. By 2007, Chinese wheat farmers were using herbicides on 55% of the nation's wheat acres [44]. Weed infestation is the main cause of low wheat yields in Pakistan and India and is reported to reduce wheat production by 25-30% [45] [46]. In Pakistan, herbicides are used on 48% of the wheat acres [47]. In India, herbicides are used on 10% of the wheat acres to control grass weed species and on 20-25% of the acres to control broadleaf species [48]. Research in Pakistan has shown that a combined treatment with both broadleaf and grass control herbicides reduced weed biomass by 95% with an increase in wheat yield of 64% [49]. Wheat growers who do not use herbicides in China, Pakistan and India rely primarily on handweeding for weed control. However, shortages of labor and increased wages discourage proper handweeding with effectiveness being reduced when rains interrupt the work [50]. This method is also not very effective for heavy infestations of weeds. Recent annual increases in wheat yields in Pakistan have been attributed to increased use of herbicides [51] [52].

Until the mid-1960s, fungicide use on wheat in Europe was only exceptional. However, during the 1960s there was a growing body of evidence that diseases of wheat were causing more losses than had previously been acknowledged [53]. At the end of the 1960s the first foliar fungicides to be targeted specifically at cereal diseases were introduced. Midway through the 1970s, new fungicides were developed that significantly broadened the number of diseases that were effectively controlled. Use of foliar fungicides gradually increased until in 1979 about 26% of the cereal hectares in western Europe received at least one treatment and 50% were treated in the UK. Since the 1990s, more than 95% of wheat acres in the UK, France, Germany, Denmark, Belgium, and The Netherlands have been treated with fungicides [54]. Fungicide use has been one of the major factors accounting for the increase in European wheat yields since the 1970s.

Fungicides contribute substantially to the yield of wheat in Europe. Average responses to treatment usually range between 0.5t/ha and 2.5t/ha, though where *Septoria tritici* blotch (STB) pressure is particularly high, yield responses of 5t/ha are sometimes seen. As STB is favored by rainfall, the higher rainfall regions in the west of Europe, such as the UK and France, usually have higher yield responses to fungicides than Denmark and Sweden [55]. A recent study estimated wheat production losses, assuming no use of fungicides, would be 20% in the UK, 26% in France and 70% in Denmark [55]. In all countries, STB was the disease that caused the greatest losses without fungicides.

In recent years in Kazakhstan, yellow rust has become a major factor adversely affecting wheat yields causing grain losses of 20-60% on 10% of the wheat hectares [56]. In 2005 a state of emergency was declared in Kazakhstan when about 20% of the wheat area was affected by a severe outbreak of septoria and rust. Fungicides were used on 1.1 million hectares. In Morocco, septoria occurs across all wheat regions and it is found in all wheat fields. In some highly infected fields, yield loss was estimated to be around 50% [57]. In Russia, epidemics of septoria occur 4-5 times in every ten years and crop losses can reach 40-50% [58]. In 2006 a lack of fungicides in Russia threatened to cause a loss of wheat from 15-40% due to unchecked outbreaks of leaf rust, powdery mildew and septoria. In Turkey, a survey was carried out after the septoria epidemic of 2011 [59]. Disease was seen in 85% of the fields with mean disease severity of 27%. In the United States, fungicide tests showed an average reduction in leaf diseases, leaf spot diseases and leaf rust of 92% [60].

According to specialists at the Ministry of Agriculture, nearly half the total cultivated area in Kazakhstan is infested with weeds, including 2.5 million hectares infested with black oats. Between 1999 and 2002, farmers applied virtually no herbicides for the control of black oats on approximately 320,000 hectares. In 2003, treatment expanded to 1.0 million hectares thanks to government subsidies of about US$2 million which reduced farmers' cost of chemicals by 30 to 40 percent. Herbicide subsidies increased to nearly US$3 million in 2004 and the treated area grew to about 1.4 million hectares. Specialists report that weed infestation has decreased by about 15 percent every year since the anti-black oat campaign was launched [61]. In Poland, research with herbicides to control grass and broadleaf weed species in wheat resulted in an average control of 94% [62].

In Italy, a study of the economics of herbicide use determined that the probability of a positive net return from chemical weed control is high, between 80.5 and 97.3% [63]. Research in the UK showed a 97% reduction of weed populations in winter wheat with a combination of broadleaf and grass control herbicides [64].

In Canada, chemical weed control has been identified as the main contributing factor to increased wheat production [65]. This control has resulted not only in reduced competition from weeds, but also in better seedbed moisture because fewer cultivations are needed in the spring. Canadian research shows that a spring herbicide application reduces total weed biomass by 94% [66]. In North Dakota research, broad spectrum herbicides reduced broadleaf and grass weed populations by 95 and 97% respectively [67][68].

Problems caused by insects in wheat fields are often erratic. Most of the regional problems in wheat are localized and are more prominent in Asia, Africa and Europe. Several common aphid species attack wheat along the length of the Nile River Valley. Research has shown that wheat yield losses in of 18% occur in unsprayed bread wheat and 16% in unsprayed durum wheat [69]. High aphid populations literally desiccate wheat plants. The Hessian fly has long been a wheat pest in regions adjacent to the Mediterranean Sea in northern Africa, southern Europe, and western Asia. Especially severe economic losses have been observed in northern Africa [69].Sunn pests are widespread throughout the rainfed grain-producing areas of southern and eastern Europe, northern Africa, and southwestern and south-central Asia. Wheat plants are injured when sunn pests extract fluids from stems, leaves or developing grains thereby reducing plant vigor. Both nymphs and adults inject an enzyme while feeding that aids in dissolving plant proteins. Leaf or stem tissues surrounding the feeding site die. The enzymes remain in a dehydrated, inactive state within the kernels after the insect ceases to feed. When water is added to flour milled from infected grain, these enzymes are reactivated and destroy the dough's gluten Such dough lacks adequate gluten strength and cannot be used to make bread [69].If as little as 3% of the grain is in such a condition, it is enough for the whole grain lot to be considered unacceptable for any baking purposes [70]. Research has shown that properly-applied insecticides can provide 100% control of sunn pests [70].

In recent years, insecticides have been used on 80% of the wheat acres in the UK mainly to target aphids and the orange wheat blossom midge [71]. The direct effects of cereal aphids on cereal yields were not appreciated until five trials showed an average 33% increase in yield in response to a single insecticide spray [72].

A serious outbreak of damage caused by orange wheat blossom midge larvae was first noticed in areas of eastern and southern England in 1993. Crop losses of over 50% were estimated in the worst cases [73]. In 1994 the return in increased yield produced by spraying produced a 1:5 cost benefit ratio [73]. In areas where effective spray action was not taken, damage increased by 50% from 1993 levels. The orange wheat blossom midge has occurred as a serious problem in parts of the UK every year.

Research has shown that insecticides provide 98% control of Hessian Fly and 87% control of aphid populations [74] [75].

Worldwide estimates of actual wheat crop production losses in 2001-2003 were estimated at 7.7% for weeds, 7.9% for "animal" pests (mostly insects), and 12.6% for pathogens and viruses [7]. Total actual wheat production loss for the world due to pests was estimated at 28.2% [7]. Table 12 displays the 2001-03 loss estimates by region [12].

The loss estimates for 2001-03 are lower than previous estimates for 1988-90 which totaled at 34% of total worldwide wheat production lost to pests (Table 13) [7][9].

Estimates have been made of the potential yield losses in wheat production by region if no measures are used to manage pests [12]. These estimates are shown in Table 14.The potential worldwide loss in wheat production from uncontrolled pests totals 50% which implies that current control measures prevent 44% of the potential loss from occurring (Table 12/Table14). For example, worldwide potential wheat yield loss to weeds (23%) (Table 14) have been reduced to 7% (Table 12) through the use of herbicides and handweeding.

The potential for a complete adoption of chemical controls to further reduce yield losses due to pests depends on the efficacy of the chemical control products against the major pest species in the region. Chemical control efficacy estimates for each region have been collected from the literature for pathogens, insects and weeds and are shown in Table 15. Table 15 only includes regions where at least one country has more than 1,000,000 hectares of wheat.Table 16 identifies the countries assigned to each region.

Tables 17, 18, and 19 contain estimates of the potential gain in wheat production from the full adoption of chemical controls to manage pathogens, insects and weeds respectively. These estimates are calculated by first estimating the amount of loss in production that would occur even with full adoption. These estimates are calculated by multiplying the estimates of the potential losses assuming no control by the estimates of 100 minus control efficacy. Next, the estimate of loss amount remaining with full control is subtracted from the estimate of current losses to calculate the amount that would be gained with adoption.

By summing across all regions and the three pest categories (pathogens, insects, weeds) an estimate is made of the total potential yield gain from adoption of chemical controls of wheat pests: (Table 20): 142.9 million tons for a 22% increase in global wheat production.

Maize

1. Asia

Traditionally, maize has been grown in Asia primarily as a subsistence food crop. In recent years, the per capita consumption of maize as a food crop has declined while the use of maize as a feed crop for livestock has increased. Seven Asian countries have more than one million hectares planted to maize.

A recent Study estimated that insects and diseases are a serious constraint on half of the maize hectares in Asia (exclusive of China) [76]. The average yield gain by removing insect and disease constraints was estimated at 14%. In China, insects and diseases are a severe constraint on about 25% of the maize area with an estimated yield increase of 40% if removed as problems [76].

Fungicides

The downy mildew diseases have been a major limiting factor in production of maize in Asia since the early 1900s. Java downy mildew is of great importance in Indonesia, where depending on the year, 20-80% of the total maize harvests are being lost as a result of downy mildew damage [77]. Philippine downy mildew is the most serious downy mildew disease in the Philippines, where the damage usually affects 40-60% of the total maize yield [77]. Brown stripe downy mildew incidence is greatest in regions of high rainfall in India and has been reported from most maize-growing regions of that country with yield losses ranging from 20-90% [78].

Downy mildew infections occur both as a result of soil borne overwintering spores which infect young plants and from spores produced by nearby infected hosts such as sugarcane or other grasses. Once inside maize plants, the fungus moves systemically throughout the plant. Infected leaves show discolored streaks and have a mildew growth which becomes a source of spores that spread the disease to other plants. Most of early infected plants usually die within a month. When cobs are formed, they are small and poorly-filled. Infected plants have weak and thin stems and poor root growth.

Research has demonstrated that systemic fungicides applied as seed treatments and/or foliar sprays provide excellent control of downy mildew [79]. Yield increases of 8-10% are possible through seed treatment alone [80]. Research has shown that seed treatment combined with one foliar spray to control brown stripe downy mildew increased maize yield by 34% [81]. Seed treatments protect young seedlings from soil-borne spores; as the fungicide is taken up systemically in the developing seedling, young plants are protected from spores moving into the crop [82].

Fungicides are widely-used on maize crops in China, Thailand and Vietnam, but are used on less than 5% of the maize hectares in India, Indonesia and the Philippines [83] [84]. Recently, as a result of higher maize prices in India, seed treatments to control downy mildew are being recommended to farmers [85].Research in India demonstrated that foliar fungicide applications could reduce downy mildew incidence by 88% [132].

Herbicides

In Asia, maize is largely a rainy season crop. Because of warm and moist weather, a variety of grass and broadleaf weeds invade maize fields frequently even before the crop germinates. Weeds compete with maize plants for space, moisture, nutrients and light and, if left uncontrolled, can reduce maize yields by

29-74% [86]. Traditionally, manual hand weeding has been the predominant method of weed control used by maize farmers in Asia [87]. If performed with enough frequency and at the right times, hand weeding results in maize yields that are equivalent to yields with herbicides [88]. However, due to shortage of labor and frequent monsoon rains during the early growth period of maize, hand weeding is often delayed or neglected altogether [88]. As a result, severe uncontrolled weed infestations have been identified as one of the major reasons causing low maize yields in Asia [86]. In the Philippines, actual losses due to weeds in maize fields have been reported at 15-30% [89]. In India, 39 trials compared maize yields with herbicides to yields obtained with farmers weed control methods; the maize yields with herbicides were 19% higher [90].In China, herbicides are used on 44% of the maize acres[91]. Maize yield reduction due to weeds on 7 million hectares (20% of total hectares) has been estimated at 10% (2% of total maize area) [92].

In China, the inability to weed on time has been identified as a major reason for the gap in maize yields in 9 out of 12 villages [93]. In India, research demonstrated that herbicide treatments in maize produced 83% more yield in comparison to the farmer practice of "seeling" in which farmers plough the fields to remove weeds [94]. Herbicide use on maize is low in India, Pakistan and the Philippines as most farmers manually weed fields [87] [83]. In a weed control experiment in Pakistan, 40 person days of labor per hectare of weeding was required to produce maize yields equivalent to herbicide treatments [87]. In Pakistan, maize yield losses due to weeds has been estimated at 14% [95[.Maize farmers in Thailand, Vietnam, and Indonesia use herbicides extensively [83]. In Thailand, most farmers apply preemergence and postemergence herbicides to maize fields [96]. In the Philippines, herbicides are very seldom used in maize fields [84]. In India, weeds are ranked as the worst production constraint by maize farmers and herbicides are not used [97].Research in Pakistan demonstrated that the use of herbicides in farmer's fields reduced weed populations by an average of 91% [94].

Insecticides

The Asian corn borer is a principal limiting factor in maize production in Southeast Asia. It has been reported as a serious pest of maize in Vietnam, China, Indonesia, Thailand, and the Philippines [98]. One of the major reasons for the low productivity of maize in India and Pakistan is damage by insects, notably stem borers [99]. Stem borer damage to maize represents a significant constraint on maize production by damaging the vascular tissue of the plant and providing a portal of entry for stalk and ear rots. The destruction is caused by the larvae which after hatching, feed on leaves, and then bore their way downward into the stem. Severe infestations of maize borers can result in 75% crop loss [95].

Maize in China is annually attacked by the Asian corn borer. Despite consistent losses estimated at 6 to 9 million tons for an ordinary year, farmers do not aggressively manage ACB with insecticide applications [101] In most maize –growing regions in China, a potential yield gain of 5-10% is expected by controlling corn borers [93].

Insecticides are not widely used in maize in India and Pakistan [83] [97]. In India stem borers are estimated to cause maize yield loss of 7.5% on 80-100% of the maize acres[97].In Pakistan, maize yield losses due to insects total 18% [95]. Insecticides are used extensively in maize in Indonesia and Thailand [83] [102].

Most Philippine maize farmers mention the Asian corn borer as an annual problem [84]. Average historical (1988-2005) yield losses in maize due to corn borer in the Philippines averaged 16% [103]. Maize yield loss in Vietnam due to borers totals about 4% annually [100].

Insecticides are effective when used at the period of borer egg hatching and the first three instars, before the larvae enter the stem [99]. Insecticidal seed treatment followed by granular applications in the whorl increased maize yield by 92% in experiments in Pakistan [95]. Experiments in the Philippines demonstrated that granular insecticide applications in the whorls increased maize yield by 61% [98].

Research in Pakistan demonstrated that insecticides could reduce borer populations by 94% [95].

2. Africa

Fungicides

Grey leaf spot is considered one of the principal constraints to maize production in sub-Saharan Africa. In Africa, grey leaf spot was first observed causing economic losses in maize fields in South Africa during the 1990/91 growing season. Since then, the pathogen has been reported as being widespread in Ethiopia, Kenya, Malawi, Mozambique and Zimbabwe and to a lesser extent in the Congo, Nigeria, Tanzania and Zambia. A plausible explanation for the sudden appearance of grey leaf spot in Africa is that infested maize residue accompanying maize imports from the USA was the original source of the fungus [104]. Grey leaf spot of maize is caused by the fungus *Cercospora zeae-maydis* which is known to infect only maize. It overwinters on infested maize residues. Following periods of high humidity, the fungus produces spores in infested debris in the spring. The spores are then wind-blown to infect newly-planted maize crops. Losses associated with grey leaf spot occur when photosynthetic tissue is rendered nonfunctional due to lesions and/or the blighting of entire leaves [104]. The blighting and premature death of leaves severely limits radiation interception as well as the production and translocation of photosynthate to developing kernels. Additional losses due to grey leaf spot occur when photosynthate is diverted from the stalk and roots, which then may predispose these tissues to stalk and root rots resulting in stalk lodging [104].

In Malawi, maize yield losses of 29-69% due to grey leaf spot have been reported [105]. A survey conducted in western Ethiopia indicated an estimate of yield losses due to the disease ranging from 22 to 75% for both improved and local varieties [106]. Grey leaf spot was first reported in Kenya and Zimbabwe during the 1995 growing season, when small scale maize farmers experienced significant yield losses. Small-scale farmers have continued to experience considerable yield losses estimated at 35% in Zimbabwe and 45% in Kenya [107]. A crop loss assessment carried out in Tanzania indicated that the disease caused grain losses ranging from 15 to 40% [108]. In South Africa, grain yield losses due to grey leaf spot are usually between 30 to 40% [109].

Fungicides have been found to provide excellent control of grey leaf spot. Few hybrids have sufficient resistance to prevent yield losses due to grey leaf spot. Research in South Africa has demonstrated that even the most resistant hybrids respond to fungicide treatment. Yield losses up to 50% have occurred in unsprayed hybrids with moderate resistance as opposed to 65% yield reductions in unsprayed susceptible varieties [104]. In seasons less conducive to grey spot disease development, yield losses in unsprayed susceptible and moderately resistant varieties were 38 and 20% respectively [104]. In tests in Zambia, grain yield differences in sprayed and unsprayed treatments ranged from 27 to 54% depending on the susceptibility of the genotype [110]. Approximately 25% of South Africa's maize hectares are treated with fungicides-mostly large commercial farms [83]. Fungicide sprays are typically not made on maize by smallholders in sub-Saharan Africa. Research in South Africa demonstrated that fungicides reduced the incidence of gray spot by 92%[133].

Insecticides

Stemborers are major pests of maize in all African countries south of the Sahara. The majority of maize is grown by subsistence farmers, and the yields are usually low. Damage caused by stemborers is one of the main causes of low yields [111]. Female stemborer moths lay eggs on maize leaves. The newly emerged larvae enter into the whorls of young maize plants and feed actively on the tender leaves. Later on, they feed on the growing points of young plants resulting in deadhearts [112]. In older plants the larvae bore into the stem and start tunneling. The fully grown larvae cut exit holes and emerge as moths. Plants thus affected have stunted and poor growth, reduced yield, and are more susceptible to wind lodging and secondary infections [112]. Field surveys on the stemborer complex in Kenya revealed natural infestations to be as high as 2-19 larvae/plant [113]. Infestation levels of 100% of plants are frequently observed [114]. In Mozambique, yield losses due to stemborer attack are often more than 50% in farmers' fields [114]. In Zimbabwe yield losses of 43% occur at the smallholder level [117]. In Ethiopia, stemborers collectively result in maize yield losses of 20-50% with occurrences of total crop failure [118].

Control options for managing stemborers include chemical, biological, cultural, and host plant resistance. Chemical control methods are most effective and are recommended by national agricultural extension agencies [115]. Cultural control methods, such as intercropping with non-cereals and early planting, have been used for centuries by farmers. Recent studies have shown that their impact on stemborer populations is limited. A recent survey in Kenya showed that over 90% of farmers applied wood ash, soil and tobacco snuff to control stem borers. Only about 2% of them found them to be very effective [116]. The levels of stemborer parasitism by indigenous natural enemies are not satisfactory [117]. Several attempts at biological control through the introduction of parasitic wasps failed.

Several insecticides, formulated either as granules or spray applications, are registered for stemborer control in African countries [117]. Because of their effectiveness and relative ease of application, the use of granular formulations is recommended for small scale farmers. Recent research in Kenya in 135 farm fields compared typical farmer practice with the application of a granular insecticide into the maize whorl [119]. The resulting estimate of the 4-year Study was that an average national crop loss of 13.5% was occurring due to uncontrolled stemborers which could be prevented by the use of the granular insecticides [119]. However, only about 5% of smallholder farmers in Kenya report using insecticides for stemborer [116]. In Ethiopia and Mozambique, large-scale commercial farmers rely on insecticides to control stemborers; communal and small scale commercial growers use insecticides only rarely [117][114].

Lack of effective Extension services and training for farmers hinders more widespread adoption of chemical insecticides for stemborer control. The conclusion of a recent Study was that renewed research efforts on chemical control, with smallholders as the target group, are clearly necessary [117]. Such research would focus mainly on application technologies and timing. A quick-acting insecticide is able to stop stemborer infestations quickly preventing yield losses and control stemborer populations that would otherwise infest more plants. In South Africa, stemborer problems have been reduced because of the widespread use of chemical insecticides and the planting of biotech maize varieties that contain BT toxins that are effective against stemborers. The biotech maize varieties have not been approved for planting elsewhere in Africa. Research in Ethiopia demonstrated that insecticides reduced stemborer populations by 75%[135]

Herbicides

Hand weeding is the predominant weed control practice on smallholder maize farmers in Africa. Weeds compete with maize crops for nutrients, space, light, and water thus reducing maize yield. African studies have documented that season-long weed competition causes maize yield losses of 50 to 90% [120]. Average yields obtained by smallholder farms are considerably less than yields demonstrated in African research plots utilizing best management practices. Smallholder maize yields are typically 1-2 tons per hectare in comparison to 8 tons per hectare achieved in research plots. The failure of farmers to replicate the weed control practices of the research farms is a major cause for low maize yields. At the experimental farms, it has been determined that maximum yields are achieved if maize fields are kept weed-free for the first 56 days after planting [121]. One week's delay in first weeding may reduce maize yields by one-third [122]. On most farms, weeding usually competes with other farm activities and is postponed to a later date. In Malawi, nationwide survey data suggests that one-third of the area planted to maize by smallholders is either left unweeded or weeded after the critical first six weeks [122]. Maize is generally the first crop planted and weeding becomes necessary at a time when labor is critical for planting cash crops such as groundnuts. Shortages of labor early in the season results in delayed weeding and subsequent maize yield losses of 15 to 90% due to weed competition [123].In Nigeria, maize farmers' weeding practice (one weeding) resulted in 42% yield loss in comparison to fields weeded three times [124].

The spraying of chemical herbicides to remove weeds from maize fields is an alternative to handweeding African fields. Experiments with herbicides to control weeds in maize crops have been conducted in sub-Saharan Africa since the 1960s. Smallholder farmers in Africa generally do not use herbicides with less than 5% adoption [125][126]. Although herbicides have been extensively studied in Africa, there has been no mechanism to disseminate the technology to smallholders once the research process was over.

Maize yields doubled in Nigeria when atrazine was used [127]. In Zimbabwe, research with herbicides resulted in yield increases of up to 50% in maize [128]. Use of herbicides in Kenyan weed trials resulted in 33% higher maize yields than farmer practice of handweeding due to better weed control [129].

The adoption of herbicides in African maize fields is likely to lead to increased production due to not only improved weed control but also by facilitating the adoption of fertilizer use and expansion of planted acres. Despite being promoted for 40 years, fertilizer use in sub-Saharan Africa remains low with only 5% of smallholders adopting their use [130]. The benefits of fertilizer depend on weed control. The application of fertilizers causes more weeds to grow which, in turn, increases the need for more hand weeding. By controlling the weed problem with herbicides, maize farmers will be more likely to use fertilizers for even greater maize yield increase. African farmers often plant only 50% of their available fields to crops, leaving the remaining area fallow, because they make a determination that not enough labor would be available to weed the additional fields [131]. By greatly reducing the amount of labor required for weeding, the adoption of herbicides can lead to a greater area planted to crops including maize. Research in Nigeria demonstrated that herbicides reduced weed dry matter by 92% [134].

CIS/Europe/N. America

The use of foliar fungicides on maize has increased greatly over the past ten years in the U.S., Brazil and Canada[136].Fungicides are usually applied by air at maize flowering to control several foliar diseases such as gray leaf spot, common rust and northern corn blight. Research in Italy demonstrated a reduction in the incidence of northern corn leaf blight of 86% with fungicide treatment [136].Fungicides provided about 71% control of diseases in maize experiments in Illinois [140].

In the Ukraine weed control in maize plots at 30 days after treatment with herbicides averaged 90% [137].In France, research demonstrated a reduction of dry weed biomass of 99% in the standard herbicide program [138]. Research in the U. S. showed 99% control of weed species in corn with combinations of herbicide active ingredients [142].

The most important insect pest of maize in Europe is the European Corn Borer. This pest is present in all areas of Europe except the northern part of Scandinavia and Great Britain. Under European conditions, chemical insecticides provide about 75% control of the borers [139]. In the U.S. growers are advised to expect 80% control of first generation borer larvae and 67% control of second generation larvae with chemical insecticides [141].

Worldwide estimates of actual maize crop production losses in 2001-2003 were estimated at 10% for weeds, 10% for “animal” pests (mostly insects),and 11% for pathogens and viruses [7]. Total actual maize production loss for the world due to pests was estimated at 31% [7]. Table 21 displays the 2001-03 loss estimates by region [12].

The loss estimates for 2001-03 are lower than previous estimates for 1988-90 which totaled at 38% of total worldwide maize production lost to pests (Table 22) [7][9].

Estimates have been made of the potential yield losses in maize production by region if no measures are used to manage pests [12]. These estimates are shown in Table 23.The potential worldwide loss in maize production from uncontrolled pests totals 69% which implies that current control measures prevent 55% of the potential loss from occurring (Table21/Table23). For example, worldwide potential maize yield loss to weeds (41%) (Table 23) have been reduced to 10% (Table 21) through the use of herbicides and handweeding.

The potential for a complete adoption of chemical controls to further reduce yield losses due to pests depends on the efficacy of the chemical control products against the major pest species in the region. Chemical control efficacy estimates for each region have been collected from the literature for pathogens, insects and weeds and are shown in Table24. Table 24 only includes regions where at least one country has more than 1,000,000 hectares of maize. Table 25 identifies the countries assigned to each region.

Tables 26, 27 and 28 contain estimates of the potential gain in maize production from the full adoption of chemical controls to manage pathogens, insects and weeds respectively. These estimates are calculated by first estimating the amount of loss in production that would occur even with full adoption. These estimates are calculated by multiplying the estimates of the potential losses assuming no control by the estimates of 100 minus control efficacy. Next, the estimate of loss amount remaining with full control is subtracted from the estimate of current losses to calculate the amount that would be gained with adoption.

By summing across all regions and the three pest categories (pathogens, insects, weeds) an estimate is made of the total potential yield gain from adoption of chemical controls of maize pests: (Table 29): 161 million tons for a 20% increase in global maize production.

Table 1. Actual Yield Losses Due to Pests, Tropical Asia: Rice	
	% Loss
Diseases	
Sheath Blight	6.1
Bacterial Leaf Blight	0.2
Tungro	0.0
Brown Spot	5.0
Leaf Blast	5.0
Neck Blast	0.3
Insects	
Whorl Maggot	0.3
Dead Hearts (Stemborers)	0.1
White Heads (Stemborers)	2.3
Weeds	
Above rice canopy	23.0
Below rice canopy	21.1
Combined	**37.2**

Table 2. Actual Yield Losses Due to Pests: Yunnan, China: Rice	
	% Loss
Diseases	
Bacterial Leaf Blight	1.2
Leaf Blast	1.5
Neck Blast	0.2
Bakane	0.7
Sheath Blight	0.5
Insects	
Plant Hoppers	1.1
Army Worms	1.8
Leaf Folders	2.1
White Heads (Stemborers)	3.0
Weeds	
Above rice canopy	2.8
Below rice canopy	1.5
Combined	**13**

Table 3. Estimated Actual Yield Losses (%) Due to Rice Pests (2001-2003)					
	Pathogens	**Viruses**	**Animal Pests**	**Weeds**	**Total**
Africa					
N. Africa	4.71	0.00	7.54	4.71	16.97
W. Africa	16.06	0.80	17.66	16.06	50.58
E. Africa	16.19	1.62	16.19	14.57	48.57
S. Africa	12.44	1.66	18.24	12.44	44.77
America					
N. America	7.36	0.00	9.20	6.44	23.00
C. America	10.39	1.73	12.99	10.39	35.49
S. America					
N. Region	10.33	2.58	12.91	10.33	36.15
S. Region	12.63	2.53	12.63	12.63	40.43
Asia					
Near East	10.45	0.87	15.68	8.71	35.71
South Asia	12.59	1.68	18.47	10.08	42.82
Southeast Asia	10.39	1.73	15.58	8.66	36.35
East Asia	8.96	0.90	11.65	7.17	26.68
Europe	8.08	0.19	8.60	7.33	24.20
Oceania	7.46	0.00	7.46	4.66	19.59
World	10.81	1.43	15.11	8.93	36.28

Table 4. Estimated Actual Losses in Worldwide Rice Production (%)		
	1988-1990	**2001-2003**
Diseases	15.0	12.2
Animal Pests	21.0	15.1
Weeds	16.0	10.1
Total	52.0	37.4

Table 5. Estimated Potential Yield Losses (%) Due to Rice Pests					
	Pathogens	**Viruses**	**Animal Pests**	**Weeds**	**Total**
Africa					
N. Africa	14.30	.71	20.01	39.31	74.34
W. Africa	12.78	.71	19.89	46.16	79.54
E. Africa	12.91	1.43	17.93	46.63	78.91
S. Africa	12.81	1.42	19.93	42.70	76.86
America					
N. America	14.51	.73	15.97	47.17	78.38
C. America	12.93	2.15	17.96	43.10	76.14
S. America					
N. Region	10.96	2.19	18.27	43.84	75.27
S. Region	13.04	2.17	18.11	39.84	73.16
Asia					
Near East	10.71	.71	22.85	42.84	77.11
South Asia	12.36	1.37	26.09	37.76	77.58
Southeast Asia	13.68	2.05	23.94	37.62	77.30
East Asia	14.90	2.03	25.74	33.87	76.55
Europe	12.92	.75	16.38	40.29	70.34
Oceania	9.52	.79	14.28	39.68	64.28
World	13.52	1.75	24.62	37.14	77.03

Table 6. Chemical Control Efficacy for Rice Pests (% Reduction)			
	Pathogens	**Insects**	**Weeds**
Africa			
N. Africa			89 [17]
W. Africa			97 [27]
E. Africa			96 [26]
America			
N. America		95 (RWW) [23] 94 (Stemborers) [28]	93 [25]
S. America-N			98 [24]
Asia			
Near East			
South Asia	90 (Blast) [21]		92 [14] [15] [16]
Southeast Asia			95 [19]
East Asia	90 (Blast) [20] 85 (Sheath Blight) [22]		96 [18]
Average	87	95	95

Table 7. Countries: Rice Pest Control Assessment		
	Area (1000 HA)	**Production (1000 MT)**
N. Africa		
Egypt	700	4330
W. Africa		
Guinea	831	1499
Mali	500	2308
Nigeria	2170	4300
Sierra-Leone	675	1027
E. Africa		
Madagascar	1340	4500
Tanzania	1000	2000
N. America		
USA	1059	8391
S. America-N		
Brazil	2427	11600
Near East		
Iran	560	2288
South Asia		
Bangladesh	11750	51005
India	44100	156496
Myanmar	6500	16900
Nepal	1560	4354
Pakistan	2750	9751
Sri Lanka	1262	4869
Southeast Asia		
Cambodia	2767	6669
Indonesia	12160	57480
Laos	820	3070
Malaysia	675	2548
Philippines	4579	16984
Thailand	11000	31000
Vietnam	7635	42776
East Asia		
China	29996	201000
Japan	1576	10503
Korea-N	570	2425
Korea-S	854	6136

Table 8. Estimated Potential Yield Gain from Chemical Control of Rice Pathogens							
						Potential Gain	
	Production (1000 MT)					**%**	**(1000 MT)**
Africa							
N. Africa	4330						
W. Africa	9134						
E. Africa	6500						
America							
N. America	8391						
S. America-N	11600						
Asia							
Near East	2288						
South Asia	243375						
Southeast Asia	160527						
East Asia	220064						
World	666209						

Table 9. Estimated Potential Yield Gain from Chemical Control of Rice Insects							
	Production (1000 MT)	Potential Loss (%)	Control Efficacy (%)	Loss with Control (%)	Actual Current Loss (%)	Potential Gain	
						%	(1000 MT)
Africa							
N. Africa	4330	20	95	1	8	7	303
W. Africa	9134	20	95	1	18	17	1553
E. Africa	6500	18	95	1	16	15	1040
America							
N. America	8391	16	95	1	9	8	671
S. America-N	11600	18	95	1	13	12	1392
Asia							
Near East	2288	23	95	1	16	15	343
South Asia	243375	26	95	1	18	17	41374
Southeast Asia	160527	24	95	1	16	15	24079
East Asia	220064	26	95	1	8	7	15404
World	666209					(13)	86159

Table 10. Estimated Potential Yield Gain from Chemical Control of Rice Weeds							
	Production (1000 MT)	Potential Loss (%)	Control Efficacy (%)	Loss with Control (%)	Actual Current Loss (%)	Potential Gain	
						%	(1000 MT)
Africa							
N. Africa	4330	39	89	4	5	1	43
W. Africa	9134	46	97	1	16	15	1370
E. Africa	6500	47	96	2	15	13	845
America							
N. America	8391	47	93	3	6	3	252
S. America-N	11600	44	98	1	10	9	1044
Asia							
Near East	2288	43	95	2	9	7	160
South Asia	243375	38	92	3	10	7	17036
Southeast Asia	160527	38	95	2	9	7	11237
East Asia	220064	34	96	1	4	3	6602
World	666209					(6)	38589

Table 11. Estimated Potential Yield Gain From Chemical Control of Rice Pests (Total)				
	Pathogens (1000 MT)	Insects (1000 MT)	Weeds (1000 MT)	Total (1000 MT)
Africa				
N. Africa	130	303	43	476
W. Africa	1005	1553	1370	3928
E. Africa	715	1040	845	2600
America				
N. America	420	671	252	1343
S. America-N	1044	1392	1044	3480
Asia				
Near East	206	343	160	709
South Asia	26771	41374	17036	85181
Southeast Asia	12842	24079	11237	48158
East Asia	4401	15404	6602	26407
World	47534	86159	38589	172282

Table 12. Estimated Actual Yield Losses (%) Due to Wheat Pests (2001-2003)					
	Pathogens	**Viruses**	**Animal Pests**	**Weeds**	**Total**
Africa					
N. Africa	9	3	11	9	31
W. Africa	10	3	10	10	34
E. Africa	13	3	10	10	36
S. Africa	5	2	9	5	20
America					
N. America	11	3	9	7	29
C. America	6	3	7	6	23
S. America					
Andean	13	3	10	10	37
S. Cone	11	4	9	7	30
Asia					
Near East	11	3	9	9	31
South Asia	13	2	7	7	29
Southeast Asia	13	2	9	13	36
East Asia	7	3	7	6	24
CIS					
Asiatic	13	2	10	13	38
European	15	3	10	10	38
Europe					
North EU	5	2	5	3	14
North non-EU	7	3	6	6	23
South EU	9	3	6	9	27
South non-EU	9	3	7	6	25
Oceania	11	3	9	9	31
World	10	2	8	7	28

Table 13. Estimated Actual Losses in Worldwide Wheat Production (%)		
	1988-1990	**2001-2003**
Diseases	12.4	12.6
Animal Pests	9.3	7.9
Weeds	12.3	7.7
Total	34.0	28.2

Table 14. Estimated Potential Yield Losses (%) Due to Wheat Pests					
	Pathogens	Viruses	Animal Pests	Weeds	Total
Africa					
N. Africa	12	3	11	26	51
W. Africa	12	3	10	26	51
E. Africa	13	3	10	26	51
S. Africa	16	2	10	20	49
America					
N. America	14	3	10	24	50
C. America	16	3	10	22	51
S. America					
Andean	16	3	10	25	54
S. Cone	17	4	10	24	54
Asia					
Near East	14	3	9	25	49
South Asia	16	2	8	26	52
Southeast Asia	13	2	9	29	51
East Asia	16	3	10	20	49
CIS					
Asiatic	13	2	10	25	49
European	16	3	10	24	52
Europe					
North EU	20	3	7	18	48
North non-EU	17	3	7	18	44
South EU	15	3	7	21	45
South non-EU	18	3	8	22	50
Oceania	16	3	10	24	52
World	16	3	9	23	50

Table 15. Chemical Control Efficacy for Wheat Pests (% Reduction)			
	Pathogens	**Insects**	**Weeds**
Africa			
N. Africa			
E. Africa			
America			
N. America	92 [60]	87 (Aphid)[75] 98 (Hessian Fly) [74]	95(Bu) 97(g) [67] [68] 94 [66]
S. America-N			
S. America-S			
Asia			
Near East		100 (Sunn)[70]	
South Asia	98, 95 [32]		95 [49]
East Asia			
CIS			
Asiatic			
European			
Europe			
North			97 [64] 94[62]
South			
Oceania			
Average	**95**	**95**	**95**

Table 16. Countries: Wheat Pest Control Assessment		
	Area (1000 MT)	**Production (1000 MT)**
N. Africa		
Algeria	2000	2800
Egypt	1280	8400
Morocco	3040	5800
E. Africa		
Ethiopia	1500	3147
N. America		
Canada	8544	25261
USA	18496	54413
S. America-N		
Brazil	2170	5800
S. America-S		
Argentina	5000	15000
Near East		
Afghanistan	2100	2500
Iran	6800	13500
Iraq	1587	2574
Syria	1600	3850
Turkey	7700	18800
South Asia		
India	29400	86870
Pakistan	8900	24200
East Asia		
China	24200	117920
CIS		
-Asiatic		
Kazakhstan	13849	22732
Uzbekistan	1400	6300
-European		
Russia	24900	56231
Ukraine	6657	22124
Europe		
-North EU		
France	5931	40787
Germany	3298	24107
Poland	2406	9488
UK	1939	14878
-South EU		
Bulgaria	1109	3995
Hungary	1011	3763
Italy	1830	6849
Spain	1907	5611
Oceania		
Australia	14100	29500
WORLD		636201

Table 17. Estimated Potential Yield Gain from Chemical Control of Wheat Pathogens							
	Production (1000 MT)	**Potential Loss (%)**	**Control Efficacy (%)**	**Loss with Control (%)**	**Actual Current Loss (%)**	**Potential Gain**	
						%	**(1000 MT)**
Africa							
N. Africa	17000	12	95	1	9	8	1360
E. Africa	3147	13	95	1	13	12	378
America							
N. America	79674	14	92	1	11	10	7967
S. America-N	5800	16	95	1	13	12	696
S. America-S	15000	17	95	1	11	10	1500
Asia							
Near East	41224	14	95	1	11	10	4122
South Asia	110070	16	96	1	13	12	13208
East Asia	117920	16	95	1	5	4	4717
CIS							
Asiatic	29032	13	95	1	8	7	2032
European	78356	16	95	1	8	7	5485
Europe							
North	89260	20	95	1	1	0	0
South	20218	15	95	1	5	4	809
Oceania	29500	16	95	1	11	10	2950
World	636201						45224

Table 18. Estimated Potential Yield Gain from Chemical Control of Wheat Insects							
	Production (1000 MT)	**Potential Loss (%)**	**Control Efficacy (%)**	**Loss with Control (%)**	**Actual Current Loss (%)**	**Potential Gain**	
						%	**(1000 MT)**
Africa							
N. Africa	17000	11	95	1	11	10	1700
E. Africa	3147	10	95	1	10	9	283
America							
N. America	79674	10	95	1	9	8	6374
S. America-N	5800	10	95	1	10	9	522
S. America-S	15000	10	95	1	9	8	1200
Asia							
Near East	41224	9	100	0	5	5	2061
South Asia	110070	8	95	1	7	6	6604
East Asia	117920	10	95	1	5	4	4717
CIS							
Asiatic	29032	10	95	1	5	4	1161
European	78356	10	95	1	5	4	3134
Europe							
North	89260	7	95	1	2	1	893
South	20218	7	95	1	6	5	1011
Oceania	29500	10	95	1	9	8	2360
World	636201						32020

Table 19. Estimated Potential Yield Gain from Chemical Control of Wheat Weeds							
	Production (1000 MT)	Potential Loss (%)	Control Efficacy (%)	Loss with Control (%)	Actual Current Loss (%)	Potential Gain	
						%	(1000 MT)
Africa							
N. Africa	17000	26	95	1	9	8	1360
E. Africa	3147	26	95	1	20	19	598
America							
N. America	79674	24	95	1	7	6	4780
S. America-N	5800	25	95	1	10	9	522
S. America-S	15000	24	95	1	7	6	900
Asia							
Near East	41224	25	95	1	9	8	3298
South Asia	110070	26	95	1	7	6	6604
East Asia	117920	20	95	1	6	5	5896
CIS							
Asiatic	29032	25	95	1	10	9	2613
European	78356	24	95	1	10	9	7052
Europe							
North	89260	18	95	1	3	2	1785
South	20218	21	95	1	9	8	1617
Oceania	29500	24	95	1	9	8	2360
World	636261						39385

Table 20. Estimated Potential Yield Gain From Chemical Control of Wheat Pests (Total)				
	Pathogens (1000 MT)	**Insects (1000 MT)**	**Weeds (1000 MT)**	**Total (1000 MT)**
Africa				
N. Africa	1360	1700	1360	4420
E. Africa	378	283	598	1259
America				
N. America	7967	6374	4780	19121
S. America-N	696	522	522	1740
S. America-S	1500	1200	900	3600
Asia				
Near East	4122	2061	3298	9481
South Asia	13208	6604	6604	26416
East Asia	4717	4717	5896	15330
CIS				
Asiatic	2032	1161	2613	5806
European	5485	3134	7052	15671
Europe				
North	0	893	1785	2678
South	809	1011	1617	3437
Oceania	2950	2360	2360	7670
World	**45224**	**32020**	**39385**	**116629**

Table 21. Estimated Actual Yield Losses (%) Due to Maize Pests (2001-2003)					
	Pathogens	**Viruses**	**Animal Pests**	**Weeds**	**Total**
Africa					
N. Africa	7	2	9	11	29
W. Africa	14	6	19	19	58
E. Africa	13	6	17	19	55
S. Africa	10	4	13	15	42
America					
N. America	6	2	6	7	22
C. America	10	3	13	13	39
S. America					
Andean	10	3	13	13	39
S. Cone	10	3	10	13	37
Asia					
Near East	9	2	10	13	34
South Asia	14	3	16	15	48
Southeast Asia	10	2	15	17	44
East Asia	9	3	9	11	31
CIS					
Asiatic	10	2	13	17	41
European	10	3	13	13	38
Europe					
North EU	4	2	7	5	18
North non-EU	6	3	9	7	25
South EU	5	3	7	9	19
South non-EU	9	3	11	9	31
Oceania	6	2	9	7	25
World	8	3	10	10	31

Table 22. Estimated Actual Losses in Worldwide Maize Production (%)		
	1988-1990	**2001-2003**
Diseases	10.8	11.2
Animal Pests	14.5	9.6
Weeds	13.1	10.5
Total	38.3	31.2

Table 23. Estimated Potential Yield Losses (%) Due to Maize Pests					
	Pathogens	Viruses	Animal Pests	Weeds	Total
Africa					
N. Africa	8	2	17	43	69
W. Africa	14	6	19	41	78
E. Africa	13	6	17	42	77
S. Africa	11	4	16	40	72
America					
N. America	8	2	16	39	65
C. America	10	3	15	42	70
S. America					
Andean	10	3	15	42	70
S. Cone	10	3	14	43	69
Asia					
Near East	9	2	14	44	67
South Asia	14	4	18	43	76
Southeast Asia	11	2	18	44	75
East Asia	11	3	16	41	71
CIS					
Asiatic	10	2	14	43	68
European	10	3	14	39	65
Europe					
North EU	7	2	12	37	58
North non-EU	6	3	14	40	63
South	8	3	14	39	65
South non-EU	9	3	17	42	70
Oceania	8	2	14	40	64
World	9	3	16	41	69

Table 24. Chemical Control Efficacy for Maize Pests (% Reduction)			
	Pathogens	**Insects**	**Weeds**
Africa			
E. Africa		75[135]	
S. Africa	92 [133]		
W. Africa			92 [134]
America			
N. America	71 [140]	74 [141]	99 [142]
S. America-N			
S. America-S			
Asia			
South Asia	88 [132]	94 [95]	91 [94]
Southeast Asia			
East Asia			
Europe			
North-EU	86 [136]	75 [139]	99 [138]
CIS			
European			90 [137]
Average	84	80	94

Table 25. Countries: Maize Pest Control Assessment		
	Area (1000 MT)	**Production (1000 MT)**
E. Africa		
Ethiopia	2152	5400
Kenya	1800	2700
Malawi	1750	3900
Tanzania	3100	3600
S. Africa		
Angola	1200	590
Mozambique	1400	2179
South Africa	3200	11500
Zambia	1300	3200
Zimbabwe	1600	1400
W. Africa		
Congo	1350	1250
Nigeria	5150	9250
N. America		
Canada	1202	10689
Mexico	6000	18100
USA	33986	313918
S. America-N		
Brazil	15156	72731
S. America-S		
Argentina	3600	21000
South Asia		
India	8670	21570
Pakistan	1050	3000
Southeast Asia		
Indonesia	3140	8900
Philippines	2556	7130
Thailand	1010	4300
Vietnam	1100	4950
East Asia		
China	33400	192780
Europe		
North-EU		
France	1571	13975
CIS		
European		
Hungary	1061	6967
Romania	2094	9042
Russia	1550	6680
Serbia	1260	6300
Ukraine	3544	22838
World		

Table 26. Estimated Potential Yield Gain from Chemical Control of Maize Pathogens							
	Production (1000 MT)	Potential Loss (%)	Control Efficacy (%)	Loss with Control (%)	Actual Current Loss (%)	Potential Gain	
						%	(1000 MT)
Africa							
E. Africa	15600	13	92	1	13	12	1872
S. Africa	18869	11	92	1	10	9	1698
W. Africa	10500	14	92	1	14	13	1365
America							
N. America	342707	8	71	2	6	4	13708
S. America-N	72731	10	84	2	10	8	5818
S. America-S	21000	10	84	2	10	8	1680
Asia							
South Asia	24570	14	88	2	14	12	2948
Southeast Asia	25280	11	88	1	10	9	2275
East Asia	192780	11	88	1	6	5	9639
Europe							
North-EU	13975	7	86	1	4	3	419
CIS							
European	51827	10	86	1	6	5	2591
World	789839						44013

Table 27. Estimated Potential Yield Gain from Chemical Control of Maize Insects							
	Production (1000 MT)	Potential Loss (%)	Control Efficacy (%)	Loss with Control (%)	Actual Current Loss (%)	Potential Gain	
						%	(1000 MT)
Africa							
E. Africa	15600	17	75	4	17	13	2028
S. Africa	18869	16	75	4	13	9	1698
W. Africa	10500	19	75	5	19	14	1470
America							
N. America	342707	16	74	4	6	2	6854
S. America-N	72731	15	74	4	13	9	6546
S. America-S	21000	14	74	4	10	6	1260
Asia							
South Asia	24570	18	94	1	16	15	3685
Southeast Asia	25280	18	94	1	15	14	3539
East Asia	192780	16	94	1	9	8	15422
Europe							
North-EU	13975	12	75	3	4	1	140
CIS							
European	51827	14	80	3	7	4	2073
World	789839						44715

Table 28. Estimated Potential Yield Gain from Chemical Control of Maize Weeds							
	Production (1000 MT)	Potential Loss (%)	Control Efficacy (%)	Loss with Control (%)	Actual Current Loss (%)	Potential Gain	
						%	(1000 MT)
Africa							
E. Africa	15600	42	92	3	19	16	2496
S. Africa	18869	40	92	3	25	22	4151
W. Africa	10500	41	92	3	25	22	2310
America							
N. America	342707	39	99	1	5	4	13708
S. America-N	72731	42	94	3	13	10	7273
S. America-S	21000	43	94	3	13	10	2100
Asia							
South Asia	24570	43	91	4	15	11	2703
Southeast Asia	25280	44	91	4	17	13	3286
East Asia	192780	41	91	4	11	7	13495
Europe							
North-EU	13975	37	98	1	5	4	559
CIS							
European	51827	39	90	4	13	9	4664
World	789839						56745

Table 29. Estimated Potential Yield Gain From Chemical Control of Maize Pests (Total)				
	Pathogens (1000 MT)	Insects (1000 MT)	Weeds (1000 MT)	Total (1000 MT)
Africa				
E. Africa	1872	2028	2496	6396
S. Africa	1698	1698	4151	7547
W. Africa	1365	1470	2310	5145
America				
N. America	13708	6854	13708	34270
S. America-N	5818	6546	7273	19637
S. America-S	1680	1260	2100	5040
Asia				
South Asia	2948	3685	2703	9336
Southeast Asia	2275	3539	3286	9100
East Asia	9639	15422	13495	38556
Europe				
North-EU	419	140	559	1118
CIS				
European	2591	2073	4664	9328
World	44013	44715	56745	145473

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